CAMBRIDGE SYSTEMATICS

MAG Truck Travel Model Update

final report

prepared for

Maricopa Association of Governments

prepared by

Cambridge Systematics, Inc.

July 2013

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date

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1.0 Introduction

The Maricopa Association of Governments (MAG) is a Council of Governments that serves as the regional agency for the metropolitan Phoenix area. MAG is the Metropolitan Planning Organization (MPO) that oversees the transportation needs for three counties – Maricopa, Pinal and Yavapai. MAG maintains a regional forecasting model that is used for a variety of projects that include but not limited to developing long range transportation plans (LRTP), air quality and conformity analyses, transit ridership forecasting, and major investment studies. MAG continuously updates their travel model as and when new data is available.

In 2008, MAG participated in the NHTS Add-on program where household travel surveys were conducted in the MAG region. These surveys were used to update MAG's passenger model. In the same timeframe, other components such as special events model, airport model and Arizona State University (ASU) model were also updated. MAG purchased new TRANSEARCH commodity flow database for the year 2009, which was the year right after the economic downturn of 2007/2008, to develop a regional freight plan. MAG also desired to explore third-party truck GPS data for updating the internal part of the truck model. So this coupled with a keen interest to update the existing truck model led to this model update described in this report.

Organization of the Final Report

This ***Final Report*** is organized as follows:

- **Chapter 2 – Model Development Process.** This chapter provides a summary of the critical issues and concerns regarding the data used in the development of the previous model. It also lists several recommendations that were adopted to enhance the truck model.
- **Chapter 3 – TRANSEARCH Commodity Flow Database.** This chapter describes the TRANSEARCH database, its contents, suitability for this model update, and summaries of key freight flows.
- **Chapter 4 – External Truck Model Development.** This chapter describes the update of the external freight model using new TRANSEARCH database.
- **Chapter 5 – Truck GPS Data**. This chapter provides a description of the truck GPS data that was acquired for this study, and also provides details on how it was processed to construct a truck trip and tour databases.
- **Chapter 6 – Internal Truck Model Development.** This chapter discusses the development of a new light commercial truck model as well as the updates performed to the medium and heavy truck models.

- **Chapter 7 – Truck Tour-Based Model**. This chapter provides a description of the tour-based modeling framework, and its development using truck GPS data.
- **Chapter 8 – Model Calibration and Validation**. This chapter summarizes the calibration procedures for all the truck modeling components, and presents a summary of all the validation results.

2.0 Model Development Process

This chapter provides a summary of the critical issues and concerns regarding existing truck model, and key recommendations that were followed to improve the model.

2.1 Critical Data and Modeling Issues/Concerns

The existing model was updated between 2007 and 2009 using some of the state of practice modeling techniques using data collected and acquired from the state of practice data collection techniques. Though the model was robust in providing what MAG desired, there were some critical issues identified as described below:

- The 2007 surveys were good enough sample for producing trip generation rates through trip diaries and establishment surveys but there wasn't enough sample size for trip distribution models. The trip diaries are the conventional way of collecting trip distribution information such as trip lengths frequency distributions and land use to land use trip interchanges. However, these surveys are very expensive and the returns are far less.
- The previous model update did not involve updating the light commercial vehicle trip rates and trip lengths that belong to FHWA class 3. The data necessary for updating this category of trucks are often hard to collect and expensive to gather enough sample. Also, there is no direct way to validate these as the truck counts cannot distinguish class 3 commercial vehicles from non-commercial vehicles used by auto passengers.
- The 'service model' was based on the regional distribution of population, employment and total VMT in the region. This model was not calibrated to any observed data due to the lack of it.
- The existing model was developed using data collected and acquired prior to the economic downturn. There have been significant changes in the freight industry in the region such as logistical changes, increase in jobs, renewed interest in real estate market, and more consumption in general with a steadily increasing population.
- The existing model was calibrated to observe the vehicle miles traveled (VMT), and no screenline counts were available for validation. There was no data available to validate truck volumes on freeways, and so only the arterials were validated at the city level.
- The truck model is a trip-based model that considers the truck trips from different sectors to be discrete in nature with no trip chaining whatsoever.

However, this is in contradiction to the actual truck travel behavior which indulges in serving several different types of sectors and land uses.

2.2 Recommendations for the MAG Truck Model

The primary objectives of this truck model update are to collect, acquire and purchase new data for commercial vehicles of all truck classes, commodity flow database for external freight flows and new vehicle classification counts along screenlines and external stations. All these data are critical to update each of the different truck modeling components and improve the model to meet all of MAG's requirements. Here are a few highlights of this model update that were recommended based on CS' recent experiences:

- The lack of enough data to update the internal truck model was overcome with the purchase of third-party truck GPS data. CS had successfully purchased and processed truck GPS data from different commercial vendors for other projects to develop robust truck modeling parameters (rates, trip lengths, trip interchanges). The ATRI GPS data was purchased for this model update.
- CS conducted a thorough research as part of a FHWA project called the 'accounting for commercial vehicles in urban truck models'. As part of this project, several data sources were reviewed, data was compiled, and model parameters for several types of light commercial vehicles were developed. The recommendations from the FHWA project was adopted and tailored to develop a light commercial vehicle trip generation and distribution models.
- The existing 'service model' was eliminated as this sector has been adequately captured in the light commercial truck model.
- The 2009 TRANSEARCH commodity flow database was purchased that formed the new estimation database for the external model parameters. This included estimating new production and attraction equations, identifying special generators and developing external-external 'thru' trips.
- New screenlines were created that encompassed all the major freeways, state highway and major arterials in the region. Several count programs were used to compile vehicle classification counts for the external stations, screenlines and for time of day factors for trucks.

A tour-based modeling framework was developed for heavy trucks to demonstrate the use of truck GPS data, and also to move MAG's trip-based truck model to a tour-based platform in the coming years.

3.0 TRANSEARCH Commodity Flow Data

The purpose of this chapter is to document the suitability of the MAG TRANSEARCH database for use in the estimation of external truck model equations (internal-external and external-internal) and external-external freight trip tables. The TRANSEARCH database was purchased by MAG from IHS/Global Insight, and includes freight flows with a base year of 2009. The suitability of TRANSEARCH dataset is based on a thorough review of whether the trading partners, commodities, and modes reported are a reasonable representation of freight flows in 2009 as compared to an independent commodity flows database.

3.1 Review of TRANSEARCH

TRANSEARCH databases are customized for each user. Because of the limitations on file size of the Access database program in the Microsoft Office suite, TRANSEARCH was delivered as a series of Microsoft Access 2000 databases. MAG provided CS with a version of TRANSEARCH for use in the update of the truck model. This version of TRANSEARCH has a creation data of June 1, 2011. It contains freight flows to, from, within, and through the study area are the five Arizona Counties which are wholly or partially contained in the MAG model region. The database consists of the databases shown in Table 3.1.

Table 3.1 MAG TRANSEARCH Databases

MAG TS Databases
TRANSEARCH 2009.mdb
TRANSEARCH 2009 ZIP 2009-2015.mdb
TRANSEARCH 2009 ZIP 2020-2035.mdb
TRANSEARCH 2009 ZIP 2040-2050.mdb

The TRANSEARCH 2009 database has the tables shown in Table 3.2. This table also shows whether the database table represents freight flows, is supporting descriptive information, is network data, or is routing data. The flow tables will be converted to standard trip tables for use in the model. The supporting information may be used to add descriptive information to assist in the development of trip tables.

Table 3.2 MAG TRANSEARCH 2009 Tables

Table Name	Table Type
Commodities	Crosswalk
Equipment Types	Crosswalk
Highway Network	Network
Highway Routes	Routing
Modes	Crosswalk
Regions	Crosswalk
Regions by County	Crosswalk
Route Signs	Addition to Routing
Study Area	Crosswalk/Definitional
Trade Type	Crosswalk
TRANSEARCH 2009	Flow Table

The freight flow information is contained in one table, **TRANSEARCH 2009,** for flows which are not subject to disclosure agreements. Typically TRANSEARCH also contains a file **Railroad Flows 2009 – HIGHLY CONFIDENTIAL** which is developed from the Private Use Surface Transportation Board (STB) Carload Waybill file and is subject to "Rule 260 Junction" disclosure rules. This rule prevents the disclosure of information which can be used to identify individual shippers. This railroad data can only be provided to TRANSEARCH customers if permission was obtained from the appropriate state DOT, in this case the Arizona DOT. The DOT did share the data with MAG but the database was not utilized in this model update, since rail flows are not needed to develop the truck model. This omission is only noted in case other uses of TRANSEARCH (e.g., economic development) are to be explored by MAG.

The TRANSEARCH 2009 flow table contains the following information which will be used to develop truck trip tables:

- **Year.** A survey year (2009) or a forecast year (2015, 2020, 2035, 2040, and 2050).
- **Origin Region.** The origin geographic zone of the freight flow which are the following:
  - The five Arizona counties in the MAG purchase (in the TRANSEARCH 2009.mdb databases. Zip code information for these same counties are contained in flow tables in the TRANSEARCH 2009 Zip 20Y1-20Y2 databases);
  - State portions of Bureau of Economic Analysis Economic Areas (BEAs) in the U.S.;

- Census Metropolitan Areas (CMAs) or remainder of provinces in Canada; and states in Mexico; and
- The five counties defined by MAG (Maricopa, Pinal Pima, Gila and Yavapai) are considered to be the "study area" for the TRANSEARCH purchase, such that freight flows which have both and origin and destinations outside of the study area, but which pass through on highways in the "study area" are included in the flow tables.

- **Destination Region.** The destination geographic zone of the freight flow which are the same as previously described for "Origin Region".
- **STCC.** The commodity of the freight flow. It is expressed as a four digit Standard Transportation Commodity Code (STCC). This level of detail is not needed in the MAG TDM and commodity groups will be established by which the reported flows can be aggregated.
- **Mode.** The mode according to the coding convention in TRANSEARCH. The coding conventions in TRANSEARCH are as in Table 3.3. The shaded rows are modes which would only appear in the Rail Highly Confidential Flow Table which was not part of the MAG TRANSEARCH 2009 purchase.

Table 3.3 TRANSEARCH Modes

TS Numeric Mode	TS Text Code	TS Mode Name	TS Mode Group
1	CL	Rail Carload	Rail
2	IMX	Rail Intermodal	Rail
3	RAIL*	Rail NEC[a]	Rail
4	TL	Truck Truckload	Truck
5	LTL	Truck L-T-L	Truck
6	PVT	Truck PVT	Truck
7	TRUCK	Truck NEC	Truck
8	AIR	Air	Air
9	WTR	Water	Water
10	OTH	Other	Other
11	PIPE	Pipeline	Pipeline

[a] Reported only for traffic from Arizona to Canada and Mexico.

- **Tons.** This indicates the freight flow in annual tons for this record.

  This non-STB flow table also includes flows reported by equipment, and includes information to be used with the TRANSEARCH routing routines. That information will not be used in the MAG TDM and these records will be aggregated. This table also reports flow in annual Units and Value in base year U.S. Dollars (USD). However, these values are derived from the reported tons using standard tables and provide no additional information for use in the TDM.

The databases TRANSEARCH 2009 ZIP 2009-2015.mdb, TRANSEARCH 2009 ZIP 2020-2035.mdb, and TRANSEARCH 2009 ZIP 2040-2050.mdb each contain only one table, a flows table whose name is identical to the database file name. It contains all of the same information as that described for the county based flow table above except that the years in the flow table contain only the two years listed in the file name, and the inclusion of two additional fields:

- **origin zip** for all origins which are one of the five MAG "TRANSEARCH study area" counties, the 2000 Zip Code Tabulation Area[1]. For all origins which are not in the study area the field has a value of 0.
- **destination zip** for all destinations which are one of the five MAG "TRANSEARCH study area" counties, the 2000 Zip Code Tabulation Area. For all destinations which are not in the study area the field has a value of 0.

The flows for 2000 ZCTA flows in a county for a given year total to the values for three counties in the TRANSEARCH 2009 table, and all other index fields are identical to the flows by county in the TRANSEARCH 2009 flow table.

3.2 FHWA's FAF Database

The Freight Analysis Framework (FAF) integrates data from a variety of sources to create a comprehensive picture of freight movement among states and major metropolitan areas by all modes of transportation. With data from the 2007 Commodity Flow Survey and additional sources, FAF Version 3 (FAF^3) provides estimates for tonnage and value, by commodity type, mode, origin, and destination for 2007, the most recent year, and forecasts through 2040. The FAF^3

[1] ZIP Code Tabulation Areas (ZCTAs™) are a statistical geographic entity produced by the U.S. Census Bureau for tabulating summary statistics, first developed for Census 2000. This entity was developed to overcome the difficulties in precisely defining the land area covered by each ZIP Code®, which is necessary in order to accurately tabulate census data for that area. ZCTAs are generalized area representations of U.S. Postal Service (USPS) ZIP Code service areas. They represent the most frequently occurring five-digit ZIP Code found in a given area. Each ZCTA is built by aggregating 2010 Census blocks, whose addresses use a given ZIP Code. Each resulting ZCTA is then assigned the most frequently occurring ZIP Code as its ZCTA code.

Regional Database[2] for 2007 and forecasts through 2040 is available in Microsoft Access format. The database consists of the data tables and descriptive information. The records in the flow table contain the following information:

- **Fr_orig.** The foreign origin, if any, for the record. The foreign zones are those specified in the FAF and consist of 8 international zones, two of which are the countries of Canada and Mexico.
- **Dms_orig.** The domestic origin for the record. The domestic zones are the 123 FAF^3 regions covering the United States. The zones as defined by FAF^3 are:
  - The state portion of 33 metropolitan regions, which the U.S. Departments of Transportation (U.S. DOT) and Commerce (USDOC) consider to be significant generators of national freight, where the metropolitan areas may include multiple states (for example, the New Jersey, New York and Connecticut portions of the New York City CSA are all separate FAF regions);
  - The balance of those 33 states which are outside of those metropolitan areas; and
  - Seventeen states without large metropolitan areas (the District of Columbia is a "state" portion of Washington DC metropolitan area).
- **Dms_dest.** The domestic destination for the record. The domestic zones are the same as described and defined under "Dms_orig" above.
- **Fr_dest.** The foreign destination, if any, for that record. The foreign zones are the same as those described above under "Fr_orig."
- **Sctg.** The commodity being reported in that record according the Standard Classification of Transported Goods (SCTG). This is reported at a two-digit level.
- **Dms_mode.** The modes used for domestic transportation according to the coding convention in FAF^3 are shown in Table 3.4.
- **TonsXX.** The flow in annual kilotons for that record in the year 20XX. These years include the surveyed flow in 2007 and forecast flows for 2015, 2020, 2025, 2030, 2035, and 2040.

  The FAF^3 database also reports the Value in 2007 USD for each year. It also reports the foreign inbound and outbound mode used, if any.

2 FAF3 Regional Database for 2007,http://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf3/faf3_1_1access03.mdb accessed on March 21, 2011.

Table 3.4 FAF3 Modes

FAF3 Mode Numeric Code	FAF3 Mode Name	AR SWM Mode
1	Truck	Truck
2	Rail	Carload Rail
3	Water	Water
4	Air (include truck-air)	Air
5	Multiple modes & mail[a]	IM Rail
6	Pipeline	Not Used
7	Other and unknown	Not Used

[a] This replaces the truck-rail (i.e., intermodal rail) mode used in FAF2. It also includes commodities reported as mail, and water-rail or water-truck multiple mode movements.

3.3 Comparison of MAG TRANSEARCH and FAF3 Databases

The FHWA's FAF Version 3, released in July of 2010, with a base year of 2007 is used to provide a comparison with the MAG TRANSEARCH database. The FAF was developed to provide a national database which can be used in policy evaluations of freight programs. Its level of geography is too coarse to be used in the development of the model. For example, in FAF3 the Phoenix Region is represented by a single zone. It includes all freight flows moving domestically in the United States. By contrast the MAG TRANSEARCH database has zones within the counties comprising the MAG model regions (all of Maricopa and Pinal Counties and portion of Yavapai, Gila, and Pima Counties), which are zip codes, and includes only the freight flows which pass to, from, within, and through those five counties. Since the databases cover different geographies, and were developed separately, if they agree at an aggregate level, it is assumed that TRANSEARCH compares favorably with the FAF and that it is, thus, suitable for use in developing freight flow tables for the model.

Though FAF3 and MAG TRANSEARCH databases include different units of geography, they can be aggregated to include entire states in the U.S., as well as the entire countries of Canada and Mexico. The FAF3 and TS databases use different commodity classification systems, but it was possible to convert and aggregate TRANSEARCH STCC flows as SCTG flows using a table provided by the FAF[3] It should be recognized that the correspondence between the

[2] Federal Highway Administration, Office of Freight Management, FAF2 Technical Documentation: 2002 and 2035: Report Number 8: Crosswalks for Commodities Classified under the Standard Transportation Commodity Code and the Standard

Footnote continued

commodity classifications are exact only at a detailed level (e.g., STCC07 may correspond to SCTG5), but the hierarchical classifications overlap and the crosswalk at a higher level of detail (e.g., STCC4 and SCTG2) can only be an approximation.

The databases differ in terms of which freight flows are included and how commodity movements are specified. The FAF3 includes reports of several commodities which are not included in TRANSEARCH such as municipal solid waste, farm-based agriculture shipments, crude petroleum and refined gasoline, and supplies and materials used in construction (after the original purchase). There is also a difference in how movements are treated at warehouses and distribution centers. In the FAF3 database, the focus is on the freight flow as a cargo movement. When it is moving through a distribution center, it may be reported as two movements where an origin of one movement and the destination of the next is the distribution center. In the FAF3 both of these movements are reported using the same commodity, even if the movement from the distribution center may consist of commodities moving in mixed shipments.

TRANSEARCH uses a carrier focus and reports the movement from the distribution center in mixed commodities using the TRANSEARCH's own unique "STCC" commodity as STCC 50XX. In FAF^3, this STCC50XX generally corresponds to SCTG 43 – Mixed Freight. The databases also differ in how multiple mode movements are reported. FAF3 defines a mode which includes multiple modes (e.g., truck-rail, also known as intermodal rail). TRANSEARCH reports each modal movement separately, where multiple movements include an origin and destination for the zone in which the modal transfer occurred. Due to these differences in the commodities reported, the treatment of origins and destinations, and the difference in commodity classification schemes, the similarity between the two databases cannot be expected to be exact.

The comparison of the MAG TRANSEARCH and FAF^3 databases was made at the SCTG2 level, using the modal correspondence shown in Table 3.4 (recognizing that the FAF^3 Multiple Mode category includes movement by water-rail and water–truck which are not intermodal rail), and flows between U.S. states, Canada and Mexico zones and Phoenix.

Even with the caveat that the correspondence will not be exact, the aggregation of the freight flows for MAG TRANSEARCH and the FAF^3 show very similar flow patterns. The differences which exist can largely be explained by the underlying difference between the two databases. As mentioned previously, the FAF is based on a shipper centric survey. Consequently, a shipment which

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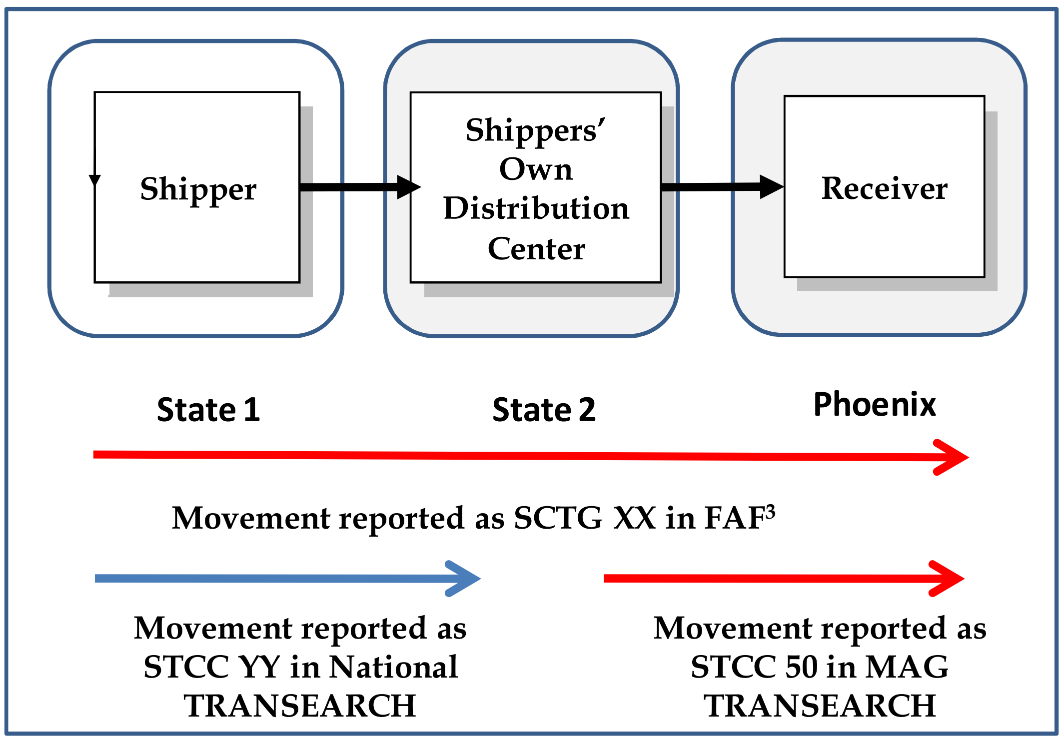
Classification of Transported Goods, available at: http://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf2_reports/data/r8_stcc_sctg.dbf, accessed on November 7, 2008, still available on April 29, 2011.

begins at a shipper in another state, travels to the shipper's own distribution center in a second state, and then to a final destination in the Phoenix region, will be shown only as a flow from the first state to Phoenix for the commodity being carried. TRANSEARCH by contrast is a carrier centric survey. It would report that exact same trip as a commodity trip from the first state to the second state, including Arizona outside of the Phoenix study area, but then as an STCC 50 trip from the second state distribution center to Phoenix. This is shown graphically in Figure 3.1. Since trips without a Phoenix origin or destination were not purchased as part of the MAG TRANSEARCH, the only record which would appear in TRANSEARCH is the STCC50 shipment from the second state to the Phoenix region.

Figure 3.1 Treatment Of Freight Shipments through a Shipper's Own Distribution Center FAF3 Versus TRANSEARCH



Additionally, many of the SCTG commodities which are reported in FAF but not in TRANSEARCH, (such as Farm-based agriculture shipment; Refined Petroleum; Municipal solid wastes; Construction; Retail; Services and Household and businesses moves), are short distance moves which will add substantially to Phoenix-Phoenix movements in the FAF. Some of the modes covered in the FAF, such as pipelines, are missing entirely from TRANSEARCH.

Despite these differences the trading patterns shown in Figures 3.2 and 3.3, and Tables 3.5 and 3.6, they are remarkably similar except for the expected favoring of short distance movements (presumably mixed freight STCC50/SCTG43) over long distance moves, and greater Phoenix to Phoenix flows. The commodities carried, as shown in Figures 3.4 and 3.5 and Tables 3.7 and 3.8, are very similar, despite the absence of certain commodities in TRANSEARCH such as Crude Petroleum, refined gasoline, and small amounts of waste because of the absence of Municipal Solid Waste and the classification of many movements as Mixed Freight SCTG43/STCC in TRANSEARCH and not in FAF^3, and the imprecision of converting the commodities in two incompatible classification systems. Finally the overall mode shares in both databases, as shown in Figures 3.6 and 3.7, are very similar.

Overall the comparison suggests that the MAG TRANSEARCH database is very similar to the overall summary of the FAF^3 for Phoenix truck traffic. To the extent that the FAF has proven useful in the evaluation of Federal policies, freight trip tables developed from TRANSEARCH for use in the MAG TDM should also prove valuable in developing the external truck portion of the MAG TDM.

FAF^3 is more useful in addressing questions of economic development because the freight trip table origins and destinations are based on the economic origination and termination of cargo at shippers and receivers. The TRANSEARCH database is more useful in addressing questions of how freight will utilize the transportation system in the Phoenix region, because the assignment will be based on origins and destinations of the vehicles carrying the cargo. It is expected that the vehicle focus of the TRANSEARCH databases will be more suitable for the purpose of developing the tuck portion of the MAG TDM.

Figure 3.2 Comparison of FAF and MAG TRANSEARCH Trading Partners All Modes: Phoenix Origin

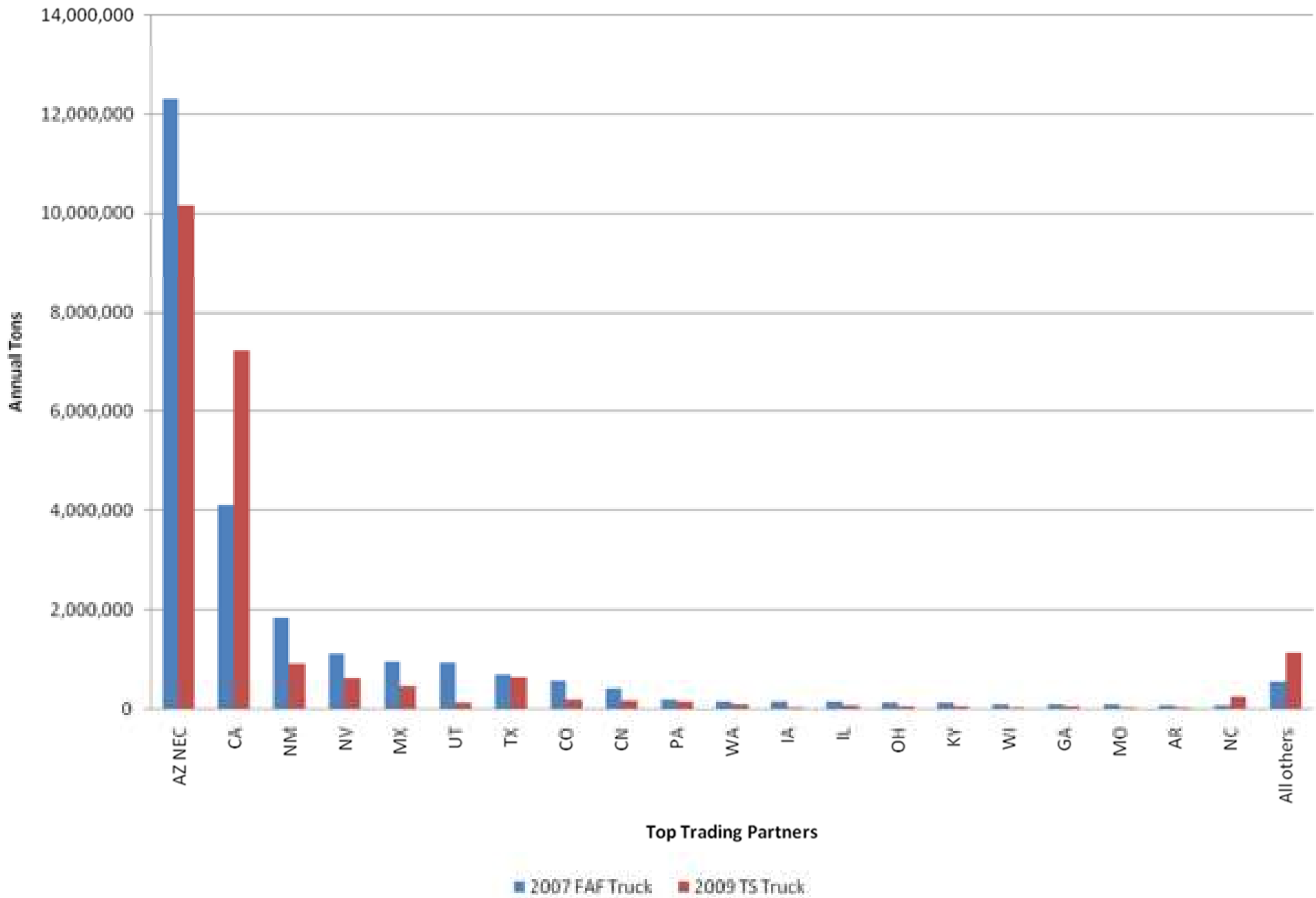


Table 3.5 Comparison of FAF and MAG TRANSEARCH Trading Partners by Mode: Phoenix Origin

	Annual Truck Tons Internal-External (Thousands)		Rank Excluding Intra Phoenix	
State Destinations	**2007 FAF Truck**	**2009 TS Truck**	**2007 FAF Truck**	**2009 TS Truck**
Phoenix	129,428,363	71,083,222	0	0
AZ Not Elsewhere Classified	12,317,363	10,163,222	1	1
CA	4,120,731	7,223,121	2	2
NM	1,832,244	913,618	3	3
NV	1,113,721	620,136	4	5
MX	960,687	457,370	5	6
UT	936,778	126,935	6	13
TX	702,918	647,576	7	4
CO	571,281	190,145	8	8
CN	413,102	162,950	9	9
PA	178,686	134,349	10	12
WA	143,548	81,087	11	18
IA	138,684	4,335	12	48
IL	135,922	59,749	13	19
OH	125,195	47,940	14	23
KY	118,235	55,530	15	20
WI	90,752	11,913	16	38
GA	90,411	49,347	17	22
MO	86,161	16,122	18	33
AR	71,740	11,051	19	39
NC	59,018	247,728	20	7
OR	58,451	13,864	21	36
NY	55,664	158,543	22	10
TN	47,041	55,294	23	21
AL	37,162	13,644	24	37
ID	28,580	7,925	25	42
FL	27,642	140,694	26	11
NJ	27,588	100,577	27	16

State Destinations	Annual Truck Tons Internal-External (Thousands)		Rank Excluding Intra Phoenix	
	2007 FAF Truck	2009 TS Truck	2007 FAF Truck	2009 TS Truck
WY	27,438	5,698	28	43
MN	26,690	13,877	29	35
MT	25,124	4,901	30	45
VA	19,230	112,479	31	14
IN	17,220	26,830	32	27
ND	15,114	2,065	33	50
OK	14,524	17,039	34	31
SC	14,445	42,534	35	24
NE	14,210	2,704	36	49
KS	13,680	8,273	37	41
LA	12,385	106,405	38	15
MD	11,810	23,964	39	28
MI	11,797	39,214	40	25
AK	11,328	15,377	41	34
SD	9,914	1,688	42	51
MA	8,056	95,389	43	17
NH	2,908	20,613	44	30
CT	2,807	29,739	45	26
MS	2,696	16,826	46	32
WV	1,533	4,472	47	47
ME	1,466	22,593	48	29
VT	1,302	4,761	49	46
HI	1,109	#N/A	50	#N/A
DE	842	5,265	51	44
RI	396	9,917	52	40
DC	343	1,245	53	52
Total (Excluding Intra Phoenix)	**24,757,672**	**22,348,634**		

Figure 3.3 Comparison of FAF and MAG TRANSEARCH Trading Partners All Modes: Phoenix Destination

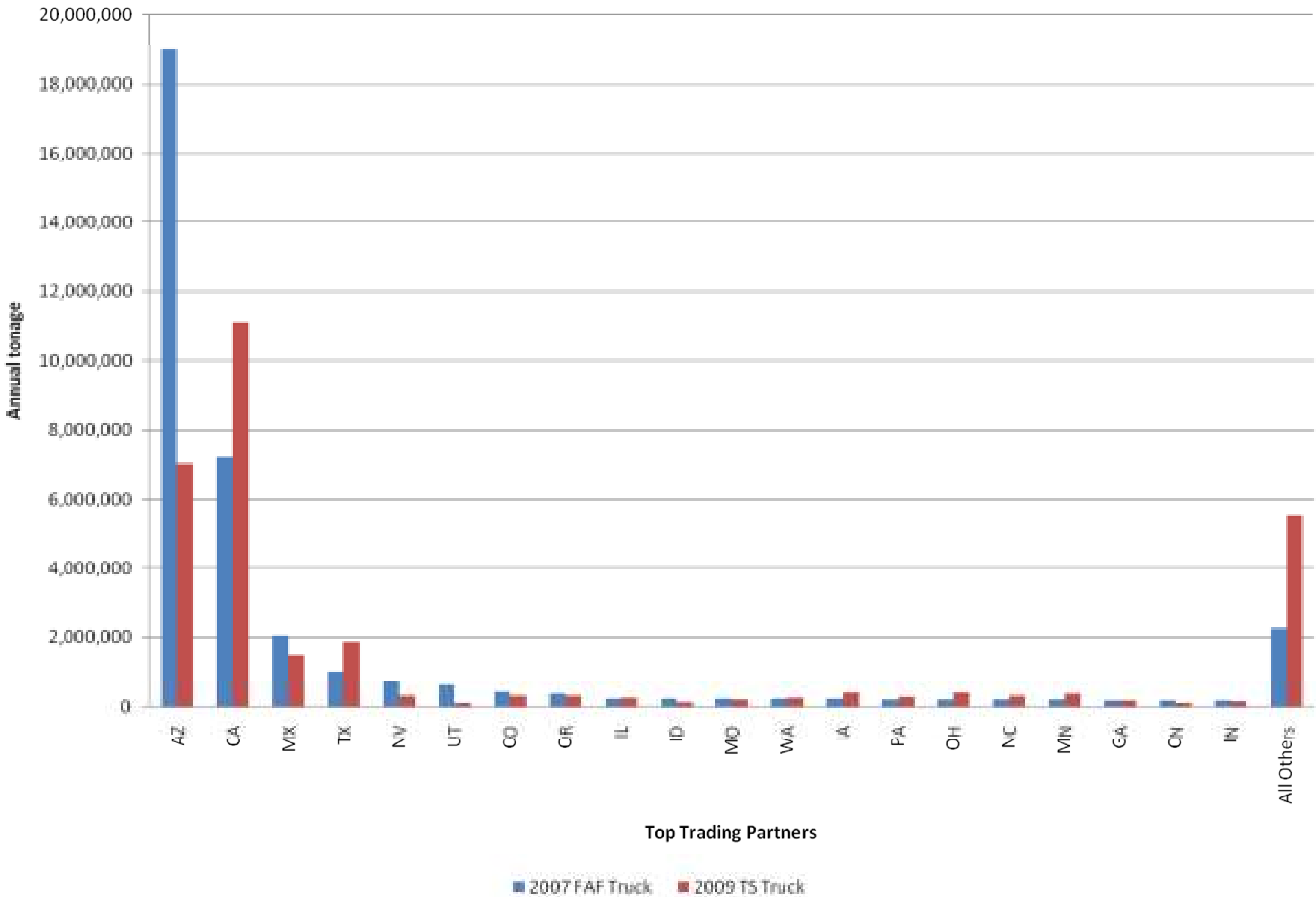


Table 3.6 Comparison of FAF and MAG TRANSEARCH Trading Partners by Mode: Phoenix Destination

	Annual Truck Tons External-Internal (Thousands)		Rank Excluding Intra Phoenix	
State Origins	2007 FAF Truck	2009 TS Truck	2007 FAF Truck	2009 TS Truck
Phoenix	129,428,363	71,083,222	0	0
AZ Not Elsewhere Classified	19,009,455	6,997,431	1	2
CA	7,212,271	11,122,766	2	1
MX	2,034,876	1,491,389	3	4
TX	1,013,229	1,862,440	4	3
NV	725,758	312,367	5	14
UT	628,884	100,909	6	37
CO	444,346	319,520	7	12
OR	362,933	319,195	8	13
IL	247,120	252,585	9	20
ID	246,685	140,532	10	28
MO	245,958	210,297	11	22
WA	234,135	270,131	12	19
IA	232,820	397,907	13	7
PA	214,984	293,367	14	16
OH	211,109	395,331	15	8
NC	205,167	309,013	16	15
MN	199,655	363,463	17	9
GA	177,384	170,378	18	25
CN	176,268	110,523	19	32
IN	171,396	147,211	20	27
TN	168,276	329,247	21	11
NM	166,839	1,262,243	22	5
WI	160,395	274,014	23	18
OK	155,867	110,233	24	33
MI	148,335	104,118	25	34
VA	141,335	95,848	26	38
AR	132,421	182,371	27	24

State Origins	Annual Truck Tons External-Internal (Thousands)		Rank Excluding Intra Phoenix	
	2007 FAF Truck	2009 TS Truck	2007 FAF Truck	2009 TS Truck
NY	125,193	357,956	28	10
AL	109,787	113,150	29	31
KS	109,171	211,881	30	21
MS	105,429	104,112	31	35
FL	100,178	59,139	32	40
NE	86,575	291,372	33	17
LA	86,255	948,422	34	6
WY	76,255	24,401	35	46
KY	74,494	125,529	36	29
NJ	67,437	168,234	37	26
WV	49,802	33,159	38	44
MT	41,731	103,491	39	36
MA	38,586	52,582	40	41
SC	24,493	80,792	41	39
MD	22,095	35,770	42	43
CT	20,194	37,346	43	42
SD	8,298	116,286	44	30
DE	7,416	22,837	45	47
ME	6,819	18,853	46	48
NH	4,642	13,979	47	49
VT	3,628	9,538	48	50
ND	2,645	203,415	49	23
RI	2,566	3,171	50	51
AK	80	32,456	51	45
Total (Excluding Phoenix)	**36,241,662**	**31,112,701**		

Figure 3.4 Comparison of FAF and MAG TRANSEARCH- SCTG2 Commodities by Truck Mode -Phoenix Origins
Base Year Annual Tons All Modes

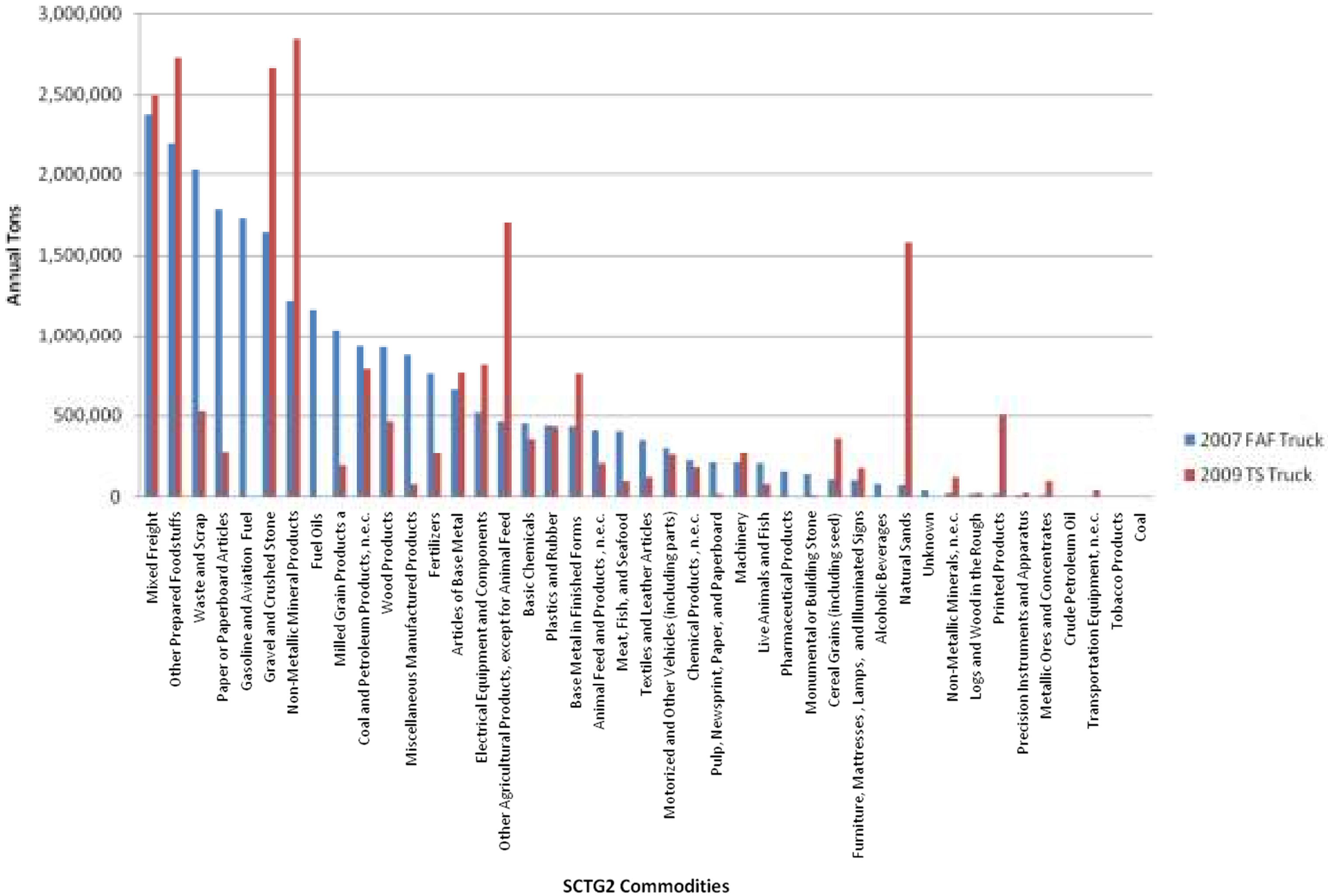


Table 3.7 Comparison of FAF and MAG TRANSEARCH – SCTG2 Commodities by Truck – Phoenix Origins

SCTG2 Commodities	Truck (Excluding Intra Phoenix) 2007 FAF Truck (Thousands of Tons)	Truck (Excluding Intra Phoenix) 2009 TS Truck (Thousands of Tons)
Mixed Freight	2,367,780	2,498,650
Other Prepared Foodstuffs, and Fats and Oils	2,194,392	2,721,073
Waste and Scrap	2,027,600	525,626
Paper or Paperboard Articles	1,791,841	282,044
Gasoline and Aviation Turbine Fuel	1,735,718	#N/A
Gravel and Crushed Stone	1,641,898	2,663,174
Non-Metallic Mineral Products	1,214,012	2,850,968
Fuel Oils	1,161,515	1,174
Milled Grain Products and Preparations, and Bakery Products	1,037,129	189,846
Coal and Petroleum Products, n.e.c.	934,763	797,912
Wood Products	924,250	467,451
Miscellaneous Manufactured Products	881,559	76,089
Fertilizers	762,697	266,691
Articles of Base Metal	667,517	773,888
Electronic and Other Electrical Equipment and Components, and Office Equipment	522,198	817,650
Other Agricultural Products, except for Animal Feed	465,234	1,705,205
Basic Chemicals	452,327	357,803
Plastics and Rubber	443,135	434,327
Base Metal in Primary or Semi-Finished Forms and in Finished Basic Shapes	435,696	763,884
Animal Feed and Products of Animal Origin, n.e.c.	411,102	203,982
Meat, Fish, and Seafood, and Their Preparations	403,805	95,902
Textiles, Leather, and Articles of Textiles or Leather	352,672	119,147
Motorized and Other Vehicles (including parts)	302,722	255,352
Chemical Products and Preparations, n.e.c.	223,595	175,832

SCTG2 Commodities	Truck (Excluding Intra Phoenix) 2007 FAF Truck (Thousands of Tons)	Truck (Excluding Intra Phoenix) 2009 TS Truck (Thousands of Tons)
Pulp, Newsprint, Paper, and Paperboard	209,653	14,493
Machinery	208,675	274,810
Live Animals and Fish	203,735	77,843
Pharmaceutical Products	154,610	#N/A
Monumental or Building Stone	135,746	8,331
Cereal Grains (including seed)	108,592	364,335
Furniture, Mattresses and Mattress Supports, Lamps, Lighting Fittings, and Illuminated Signs	101,574	173,959
Alcoholic Beverages	76,823	3,380
Natural Sands	71,745	1,578,134
Unknown	40,728	#N/A
Non-Metallic Minerals, n.e.c.	21,387	117,865
Logs and Other Wood in the Rough	17,086	23,916
Printed Products	16,452	510,600
Precision Instruments and Apparatus	11,313	22,688
Metallic Ores and Concentrates	10,268	95,506
Crude Petroleum Oil	6,545	#N/A
Transportation Equipment, n.e.c.	6,017	39,039
Tobacco Products	1,241	#N/A
Coal	327	#N/A
Total	**24,757,672**	**22,348,570**

Figure 3.5 Comparison of FAF and MAG TRANSEARCH SCTG2 Commodities: Phoenix Destinations
Base Year Annual Tons Truck Mode

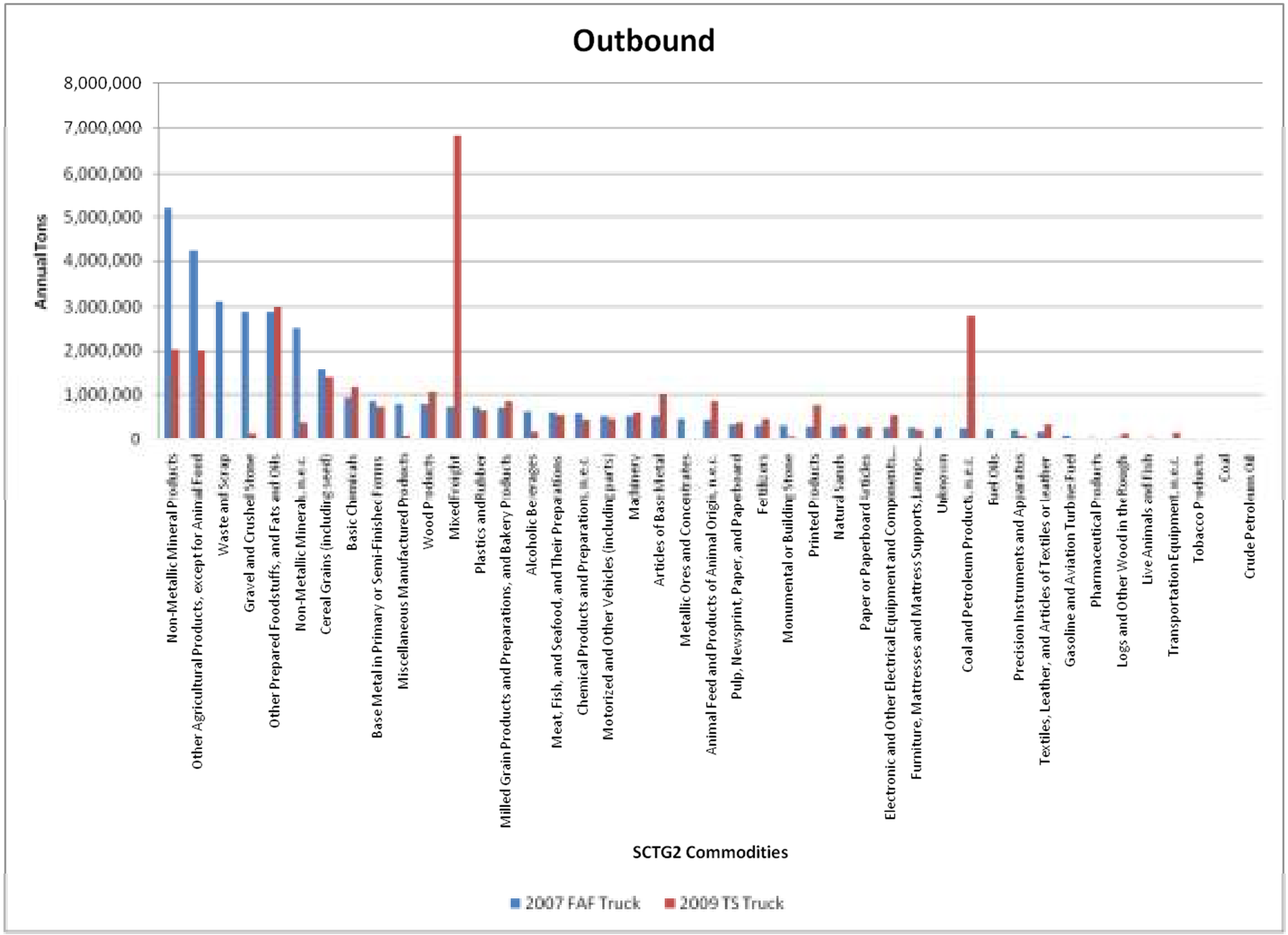


Table 3.8 Comparison of FAF and MAG TRANSEARCH SCTG2 Commodities by Truck: Phoenix Destinations

SCTG Commodities	Truck Excluding Intra Phoenix	
	2007 FAF Truck (Thousands of Tons)	2009 TS Truck (Thousands of Tons)
Non-Metallic Mineral Products	5,201,175	2,022,571
Other Agricultural Products, except for Animal Feed	4,265,006	1,994,868
Waste and Scrap	3,111,922	47,546
Gravel and Crushed Stone	2,897,812	149,062
Other Prepared Foodstuffs, and Fats and Oils	2,885,580	2,988,267
Non-Metallic Minerals, n.e.c.	2,496,642	392,043
Cereal Grains (including seed)	1,603,499	1,367,629
Basic Chemicals	924,952	1,157,496
Base Metal in Primary or Semi-Finished Forms	849,910	724,149
Miscellaneous Manufactured Products	798,055	108,814
Wood Products	794,487	1,056,750
Mixed Freight	737,862	6,815,779
Plastics and Rubber	723,319	651,187
Milled Grain Products and Preparations, and Bakery Products	705,729	854,202
Alcoholic Beverages	630,042	189,048
Meat, Fish, and Seafood, and Their Preparations	607,756	541,293
Chemical Products and Preparations, n.e.c.	580,534	445,695
Motorized and Other Vehicles (including parts)	535,789	469,205
Machinery	529,832	606,546
Articles of Base Metal	526,644	981,539
Metallic Ores and Concentrates	469,838	745
Animal Feed and Products of Animal Origin, n.e.c.	435,126	858,115
Pulp, Newsprint, Paper, and Paperboard	343,981	374,169
Fertilizers	332,050	458,965
Monumental or Building Stone	321,396	80,482
Printed Products	300,388	772,153
Natural Sands	294,037	320,156
Paper or Paperboard Articles	292,528	311,389

SCTG Commodities	Truck Excluding Intra Phoenix	
	2007 FAF Truck (Thousands of Tons)	2009 TS Truck (Thousands of Tons)
Electronic and Other Electrical Equipment and Components, and Office Equipment	283,659	541,914
Furniture, Mattresses and Mattress Supports, Lamps, Lighting Fittings, and Illuminated Signs	282,294	220,048
Unknown	281,738	#N/A
Coal and Petroleum Products, n.e.c.	261,229	2,758,431
Fuel Oils	248,304	286
Precision Instruments and Apparatus	219,316	103,779
Textiles, Leather, and Articles of Textiles or Leather	183,613	343,497
Gasoline and Aviation Turbine Fuel	98,116	#N/A
Pharmaceutical Products	65,503	#N/A
Logs and Other Wood in the Rough	59,896	139,961
Live Animals and Fish	33,944	69,219
Transportation Equipment, n.e.c.	19,222	157,482
Tobacco Products	7,011	39,169
Coal	1,918	#N/A
Crude Petroleum Oil	8	#N/A
Total Excluding Intra Phoenix	**36,241,662**	**31,113,650**

3.4 COMMODITIES IN THE MAG 2009 TRANSEARCH DATABASE

As noted in the previous sections, the MAG 2009 TRANSEARCH reports commodity flows using STCC4 commodity codes. There are over 424 STCC4 (digit) codes used to report flows, and this is far too large to support the truck model. Even the aggregation of the flows to the 32 STCC2 (digit) codes would be excessive. For the original development of the MAG external truck model, developed couple of years ago, the commodity groups shown in Table 3.9 were proposed based on a review of the flows extracted for the MAG region from the AZDOT 2005 TRANSEARCH.

Table 3.9 Assignment of STCC2 to Commodity Groups
Based on NAICS2

STCC Code	STCC Name	NAICS2 Code	NAICS2 Name	Annual Truck Units[a]	CG #	Percentage by NAICS	Commodity Group Name
1	Agriculture	11	Agriculture, Forestry, Fishing and Hunting	1,352,547	1	100%	Farm
8	Forestry	11	Agriculture, Forestry, Fishing and Hunting	3	1	100%	Farm
9	Fish	11	Agriculture, Forestry, Fishing and Hunting	242	1	100%	Farm
10	Metallic Ores	21	Mining	82	2	100%	Mining
13	Crude Petroleum	21	Mining	11	2	100%	Mining
14	Nonmetallic Minerals	21	Mining	447	2	100%	Mining
19	Ordnance	21	Mining	52	2	100	Mining
20	Food	31	Manufacturing, Consumer Non Durable	4,578,927	3	96%	Consumer
		11	Agriculture, Forestry, Fishing and Hunting	179,876		4%	
21	Tobacco	31	Manufacturing, Consumer Non Durable	4,408	3	100%	Consumer
22	Textiles	31	Manufacturing, Consumer Non Durable	117,553	3	100%	Consumer
23	Apparel	31	Manufacturing, Consumer Non Durable	702,167	3	90%	Consumer
		33	Manufacturing, Durable	76,123		10%	
		32	Manufacturing, Non Consumer Non Durable	5,953		1%	
24	Lumber	32	Manufacturing, Non Consumer Non Durable	381,407	4	47%	Lumber
		33	Manufacturing, Durable	237,458		29%	
		11	Agriculture, Forestry, Fishing and Hunting	191,319		24%	

STCC Code	STCC Name	NAICS2 Code	NAICS2 Name	Annual Truck Units[a]	CG #	Percentage by NAICS	Commodity Group Name
25	Furniture	33	Manufacturing, Durable	517,824	6	100%	Durable
26	Paper	32	Manufacturing, Non Consumer Non Durable	375,783	5	100%	Nondurable
27	Printed Goods	51	Information	660,805	7	94%	Printing
		32	Manufacturing, Non Consumer Non Durable	40,162		6%	
28	Chemicals	32	Manufacturing, Non Consumer Non Durable	2,118,176	5	89%	Nondurable
		31	Manufacturing, Consumer Non Durable	145,632		6%	
		21	Mining	63,212		3%	
		33	Manufacturing, Durable	63,212		3%	
29	Petroleum	32	Manufacturing, Non Consumer Non Durable	818,234	5	100%	Nondurable
30	Rubber/Plastics	32	Manufacturing, Non Consumer Non Durable	121,625	5	91%	Nondurable
		31	Manufacturing, Consumer Non Durable	12,378		9%	
31	Leather	31	Manufacturing, Consumer Non Durable	33,445	3	67%	Consumer
		32	Manufacturing, Non Consumer Non Durable	8,129		16%	
		33	Manufacturing, Durable	8,129		16%	
32	Clay, Concrete, Glass	32	Manufacturing, Non Consumer Non Durable	2,504,992	5	73%	Nondurable
		21	Mining	869,405		25%	
		33	Manufacturing, Durable	36,466		1%	
33	Metal	33	Manufacturing, Durable	1,348,548	6	81%	Durable

STCC Code	STCC Name	NAICS2 Code	NAICS2 Name	Annual Truck Units[a]	CG #	Percentage by NAICS	Commodity Group Name
		32	Manufacturing, Non Consumer Non Durable	324,280		19%	
34	Metal Products	33	Manufacturing, Durable	2,297,075	6	100%	Durable
35	Machinery	33	Manufacturing, Durable	1,813,420	6	98%	Durable
		31	Manufacturing, Consumer Non Durable	43,525		2%	
36	Electrical Equipment	33	Manufacturing, Durable	802,571	6	99%	Durable
		51	Information	6,392		1%	
37	Transportation Equipment	33	Manufacturing, Durable	2,959,684	6	98%	Durable
		81	Other Services (except Public Administration)	53,780		2%	
		54	Professional, Scientific, and Technical Services	19,628		1%	
38	Instruments	33	Manufacturing, Durable	208,359	6	84%	Durable
		32	Manufacturing, Non Consumer Non Durable	39,515		16%	
39	Misc. Mfg Products	33	Manufacturing, Durable	158,007	6	91%	Durable
		32	Manufacturing, Non Consumer Non Durable	15,837		9%	
		31	Manufacturing, Consumer Non Durable	487		0%	
40	Waste	48	TCU	1	8	100%	Misc. Freight
41	Misc. Freight Shipments	48	TCU	5	8	100%	Misc. Freight
42	Shipping Containers	49	Warehousing	7,324,792	9	100%	Empty trucks
50	Secondary & Warehouse	#N/A	#N/A	408,111	10	100%	Warehousing

The 10 Commodity Groups listed in Table 3.9 were eventually reduced to nine when it was found that no difference could be determined between the treatment of lumber and all other Non Durable Commodities, and therefore CGs 4 and 5 above were combined. Table 3.10 shows the tonnage flows for the base year from MAG 2009 TRANSEARCH, and the adopted commodity groupings for this model update.

Table 3.10 Tonnage of STCC2s by Current External Model Commodity Groups

STCC2 Code	STCC2 Name	CG #	Commodity Group Name	Sum Of Inbound (EI)Tons	Sum of Outbound (IE) Tons	Sum of EI & IE Tons
1	Agriculture	1	Farm	6,278,911	5,490,599	11,769,510
9	Fish	1	Farm	17,091	25	17,116
8	Forest Products	1	Farm	624	–	624
14	Nonmetallic Minerals	2	Mining	51,546,141	54,970,178	106,516,319
10	Metallic Ores	2	Mining	39,263	134,024	173,287
19	Ordnance	2	Mining	12,048	11,658	23,706
13	Crude Petroleum	2	Mining	286	1,174	1,460
20	Food	3	Consumer	6,667,241	3,805,650	10,472,891
23	Apparel	3	Consumer	127,648	21,230	148,878
22	Textiles	3	Consumer	68,845	15,004	83,850
21	Tobacco	3	Consumer	39,169	–	39,169
31	Leather	3	Consumer	25,116	868	25,984
32	Clay, Concrete, Glass	4	Nondurable	7,113,673	8,290,169	15,403,842
24	Lumber	4	Nondurable	1,981,812	1,300,736	3,282,549
26	Paper	4	Nondurable	693,541	299,890	993,430
29	Petroleum	5	Durable	7,752,001	5,444,998	13,197,000
28	Chemicals	5	Durable	2,286,093	1,117,280	3,403,373
33	Metal	5	Durable	854,316	804,644	1,658,960
34	Metal Products	5	Durable	857,199	716,217	1,573,416
36	Electrical Equipment	5	Durable	554,448	827,068	1,381,516
37	Transportation Equipment	5	Durable	706,426	386,029	1,092,455
30	Rubber/Plastics	5	Durable	610,775	437,724	1,048,499

STCC2 Code	STCC2 Name	CG #	Commodity Group Name	Sum Of Inbound (EI)Tons	Sum of Outbound (IE) Tons	Sum of EI & IE Tons
35	Machinery	5	Durable	503,473	170,778	674,251
25	Furniture	5	Durable	198,650	168,906	367,556
39	Misc Mfg Products	5	Durable	201,925	136,234	338,159
38	Instruments	5	Durable	126,528	38,803	165,330
27	Printed Goods	6	Printing	778,785	529,247	1,308,032
40	Waste	7	Misc. Freight	764,340	1,241,980	2,006,320
41	Misc Freight Shipments	7	Misc. Freight	35,139	2,149	37,288
42	Shipping Containers	8	Empty trucks	35,920	3,561	39,481
50	Warehousing & Secondary Truck	9	Warehousing	9,690,331	86,325	9,776,656
50	Rail Drayage	9	Warehousing	1,130,135	86,325	1,216,460
50	Air Drayage	9	Warehousing	85,882	86,325	172,207

It does appear that Lumber would again be worth considering as a separate Commodity Group apart from Nondurable goods, but as noted above, this separation was not supported during the development of trip generation and distribution coefficients. Similarly, Petroleum and Chemicals might now be considered as separate Commodity Groups from Durable Commodities; however, as is true for Lumber, it is likely that this separation would not be supported by the explanatory employment data. STCC 27, Printed Material which is Commodity Group 6, would not be proposed to be separated based on the tonnage it carries. Considerations should be given to combining it with other Nondurable Commodities. Finally, while the tonnage from CG 8 Empty Trucks is of course very low, this Commodity Group was found to be a function of other loaded commodity group flows and should be maintained.

Based on an examination of MAG 2009 TRANSEARCH, the commodity groups that are considered in the External Truck Model development are shown in Table 3.11.

Table 3.11 Commodity Groups

Commodity Group Number	Name	STCC2s Included	NAICS2 Industry
1	Farm	STCC 01, 08, 09	11
2	Mining	STCC 10, 13, 14, 19	21
3	All Consumer Manufacturing	STCC 20, 21, 22, 23, 31	31
4	(Non-Consumer) Nondurable Manufacturing	STCC 24, 26, 28, 29, 30, 32	32
5	(Non-Consumer) Durable Manufacturing	STCC 25, 33, 34, 35, 36, 37, 38, 39	33
6	Printing	STCC 27	51
7	Miscellaneous Freight	STCC 40, 41	4x
8	Empty trucks	STCC 42	All
9	Warehousing	STCC 50	Wholesale

3.5 Growth Rates for Forecast Years

The Commodity Groups defined in Table 3.11 were used to prepare tabulations of the tonnages flows for the base and forecast years contained in MAG 2009 TRANSEARCH. This database was used as the estimation and calibration data in the development of production and attraction equations for the internal trip end of External-Internal and Internal-External truck flows. This data was also used to develop the productions and attractions for the external trip end of these same trips. Additionally the data was used to develop the entire growth of External to External trips. The external flows was further adjusted by an Iterative Proportional Fitting adjustment based on observed truck counts at the external stations.

The total truck tonnages and compound annual growth rates are shown for the following directional markets in the following tables:

- Internal-External Truck Tons in Table 3.12 and Table 3.13;
- External-Internal Truck Tons in Table 3.14 and Table 3.15; and
- External-External Truck Tons in Table 3.16 and Table 3.17.

The total tonnage and annual growth rates by truck by directional market for all commodity groups are shown in Figure 3.6 and Figure 3.7.

Table 3.12 IE Truck Tonnage by Proposed MAG Commodity Groups

Commodity Group	2009	2015	2020	2035	2040	2050
Farm	2,917,896	3,044,534	3,141,514	3,385,425	3,459,632	3,667,720
Mining	7,437,364	10,079,687	11,690,370	14,702,699	15,791,974	18,918,903
All Consumer Manf.	2,553,661	2,982,054	3,294,204	4,485,701	4,962,337	6,110,147
(Non-Consumer) Nondurable Manf.	3,859,457	5,235,265	5,913,624	8,023,596	8,888,405	11,048,094
(Non-Consumer) Durable Manf.	5,702,156	7,559,610	8,911,490	14,340,438	16,866,451	24,251,496
Printing	528,515	507,261	515,586	677,381	765,983	985,585
Misc. Freight	547,189	964,439	1,211,364	2,361,419	3,089,218	5,248,018
Empty trucks	190	266	339	538	611	805
Warehousing	3,043,032	3,904,635	4,707,775	7,511,301	8,690,264	11,709,559
Total	**26,589,459**	**34,277,749**	**39,386,264**	**55,488,499**	**62,514,875**	**81,940,326**

Table 3.13 IE Annual Truck Growth rate by Proposed MAG Commodity Groups

Commodity Group	09 to 15	15 to 20	20 to 35	35 to 40	40 to 50	09 to 50
Farm	0.70%	0.60%	0.50%	0.40%	0.60%	0.60%
Mining	5.20%	3.00%	1.50%	1.40%	1.80%	2.30%
All Consumer Manf.	2.60%	2.00%	2.10%	2.00%	2.10%	2.20%
(Non-Consumer) Nondurable Manf.	5.20%	2.50%	2.10%	2.10%	2.20%	2.60%
(Non-Consumer) Durable Manf.	4.80%	3.30%	3.20%	3.30%	3.70%	3.60%
Printing	-0.70%	0.30%	1.80%	2.50%	2.60%	1.50%
Misc. Freight	9.90%	4.70%	4.60%	5.50%	5.40%	5.70%
Empty trucks	5.80%	5.00%	3.10%	2.60%	2.80%	3.60%
Warehousing	4.20%	3.80%	3.20%	3.00%	3.00%	3.30%
Total	**4.30%**	**2.80%**	**2.30%**	**2.40%**	**2.70%**	**2.80%**

Table 3.14 EI Truck Tonnage by Proposed MAG Commodity Groups

Commodity Group	2009	2015	2020	2035	2040	2050
Farm	5,220,998	5,522,400	5,794,219	6,921,720	7,326,507	8,443,327
Mining	3,379,104	4,030,579	4,555,718	6,853,716	7,869,754	10,458,130
All Consumer Manf.	5,528,259	6,546,777	7,240,216	9,985,906	11,042,793	13,616,299
(Non-Consumer) Nondurable Manf.	4,384,958	6,914,900	8,232,097	11,860,182	13,149,765	16,397,966
(Non-Consumer) Durable Manf.	10,012,343	13,061,922	15,205,429	23,817,566	28,149,936	41,865,416
Printing	778,053	771,609	816,905	1,137,163	1,297,387	1,699,357
Misc. Freight	88,642	112,238	129,638	192,121	216,209	278,176
Empty trucks	32,475	44,555	56,561	99,118	114,951	156,063
Warehousing	6,578,240	9,171,546	11,810,288	22,035,862	26,572,170	39,026,953
Total	**36,003,073**	**46,176,527**	**53,841,071**	**82,903,355**	**95,739,472**	**131,941,687**

Table 3.15 EI Annual Truck Growth Rate by Proposed MAG Commodity Groups between Forecast Years

Commodity Group	09 to 15	15 to 20	20 to 35	35 to 40	40 to 50	09 to 50
Farm	0.90%	1.00%	1.20%	1.10%	1.40%	1.20%
Mining	3.00%	2.50%	2.80%	2.80%	2.90%	2.80%
All Consumer Manf.	2.90%	2.00%	2.20%	2.00%	2.10%	2.20%
(Non-Consumer) Nondurable Manf.	7.90%	3.50%	2.50%	2.10%	2.20%	3.30%
(Non-Consumer) Durable Manf.	4.50%	3.10%	3.00%	3.40%	4.00%	3.60%
Printing	-0.10%	1.10%	2.20%	2.70%	2.70%	1.90%
Misc. Freight	4.00%	2.90%	2.70%	2.40%	2.60%	2.80%
Empty trucks	5.40%	4.90%	3.80%	3.00%	3.10%	3.90%
Warehousing	5.70%	5.20%	4.20%	3.80%	3.90%	4.40%
Total	**4.20%**	**3.10%**	**2.90%**	**2.90%**	**3.30%**	**3.20%**

Table 3.16 EE Truck Tonnage by Proposed MAG Commodity Groups

Commodity Group	2009	2015	2020	2035	2040	2050
Farm	23,737,932	24,592,425	25,706,009	29,773,108	31,508,944	36,776,566
Mining	14,498,404	18,865,277	21,771,891	28,174,762	30,507,624	36,901,276
All Consumer Manf.	25,772,796	29,602,807	32,494,570	43,595,111	48,353,326	59,907,472
(Non-Consumer) Nondurable Manf.	15,366,298	20,059,900	20,624,968	22,667,508	24,274,857	28,439,583
(Non-Consumer) Durable Manf.	29,686,679	39,566,953	47,031,391	77,882,989	96,036,298	157,038,388
Printing	887,736	867,519	898,759	1,216,664	1,386,230	1,810,227
Misc. Freight	7,548,794	14,842,132	19,675,580	43,902,923	60,362,811	111,582,838
Empty trucks	127,608	168,749	205,269	321,397	368,609	488,278
Warehousing	9,865,886	12,879,618	15,681,988	25,268,596	29,298,684	39,618,638
Total	**127,492,133**	**161,445,381**	**184,090,424**	**272,803,059**	**322,097,382**	**472,563,266**

Figure 3.6 Total Truck Tonnage by Direction

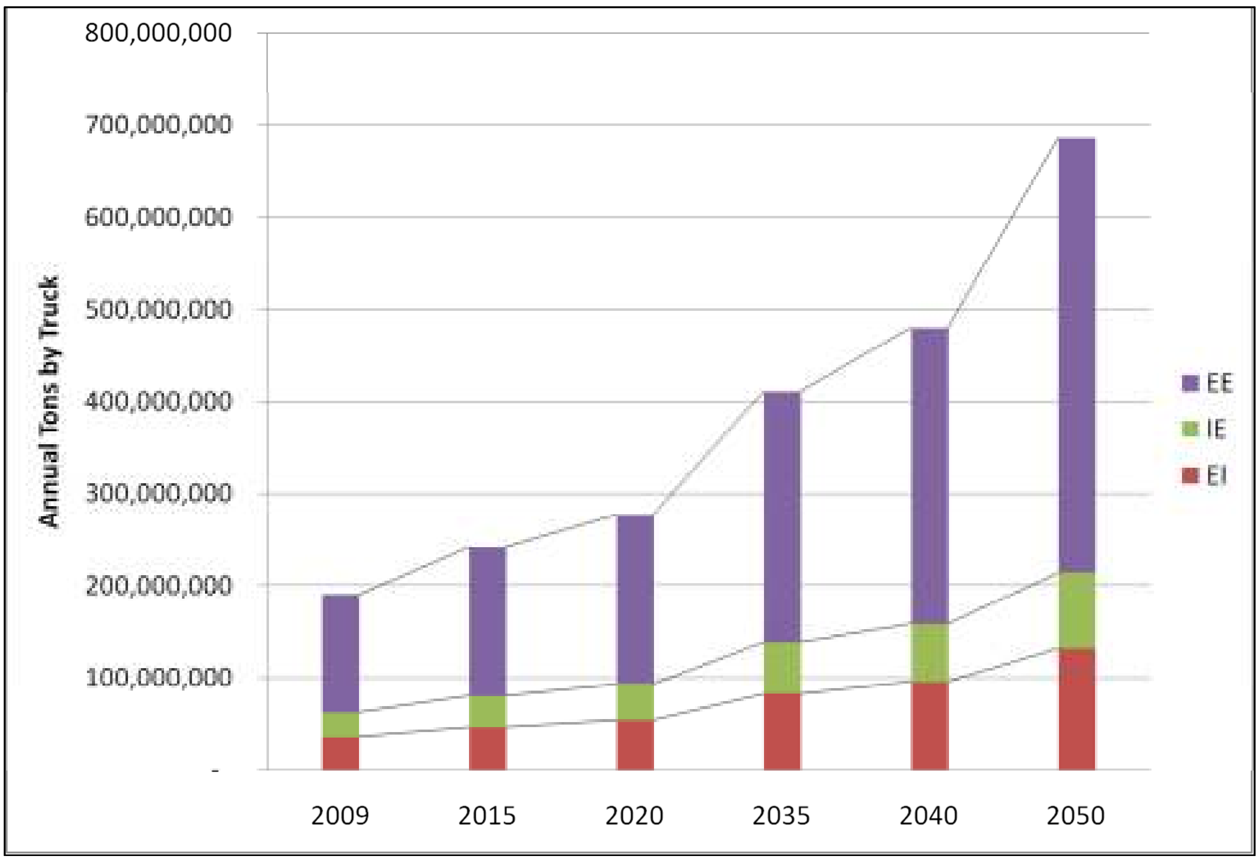
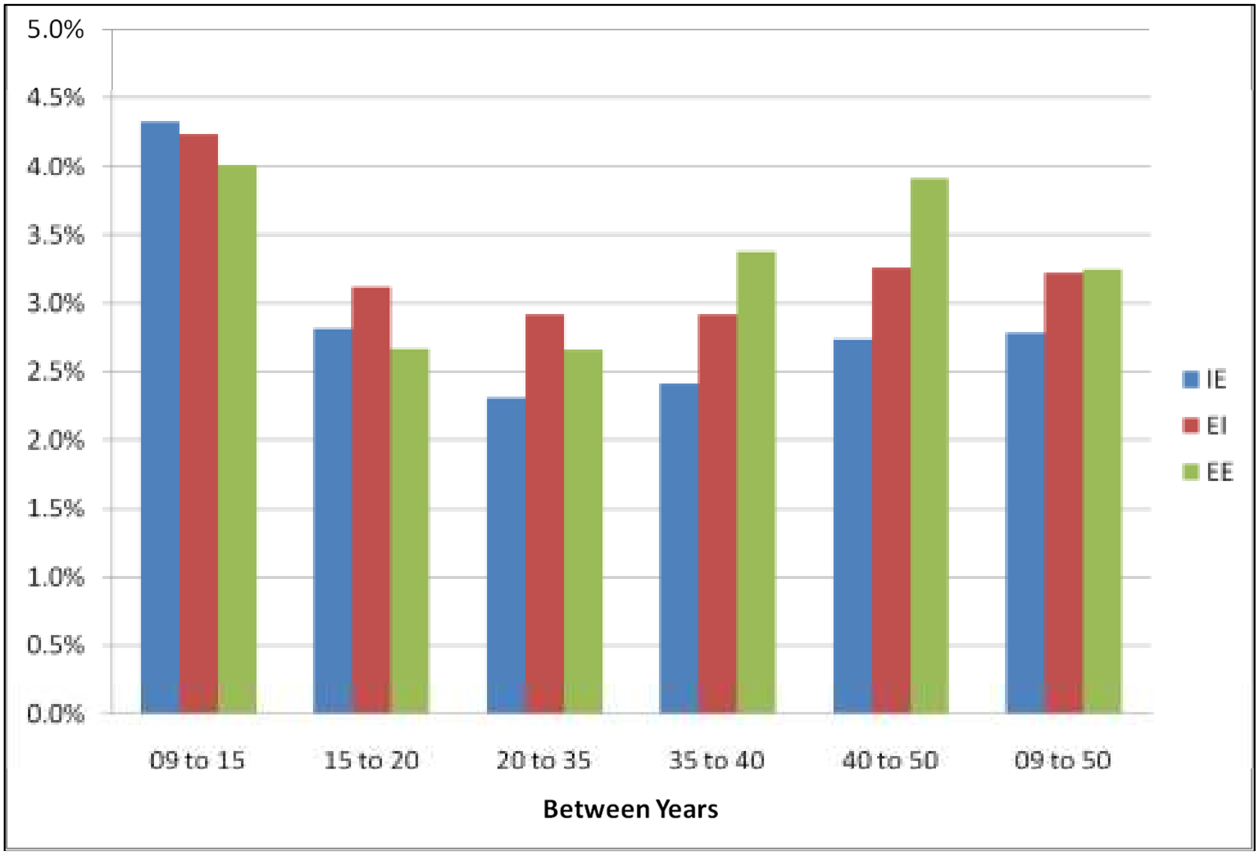


Figure 3.7 Annual Truck Tonnage Growth Rate between Forecast Years



It should be noted that while the Internal-External and External-Internal tonnages reported in these tables will be the ones which ultimately will be used as calibration/estimation data in the MAG truck model update, the External-External flows as reported by TRANSEARCH include flows which may pass through one of the MAG TRANSEARCH Study Area counties even though it would not pass through the MAG Model Region. For example truck flows between Memphis and Los Angeles which travel on I-40 through Yavapai County are considered to be External-External traffic by TRANSEARCH, even though that flow does not pass through the MAG model region. That is why the External-External flows trip table was assigned to a national highway network (the FAF3.1.1 Highway network) and windowed by subarea extraction to the MAG model region to identify external station to external station flows. Therefore, while Tables 3.12, 3.14 and 3.16, and Figure 3.6 shows that External-External truck tonnages are double the combined volumes of Internal-External and External-Internal truck tonnages, this ratio, although still expected to show considerable External-External station flows, will be lower.

It is also noted that in 2009 the Phoenix region was a net importer of truck tonnages, and that the import truck tonnages are growing at faster rate than export truck tonnages.

4.0 External Model Development

This chapter presents the methodology used for developing the external truck model that include medium and heavy trucks only. This chapter also presents the trip generation equations for productions (IE) and attractions (EI), distribution and splitting of external trucks into medium and heavy trucks, and a brief summary on the generation of special generators and external-external (EE) truck trip table.

The previous external truck model was developed using an older TRANSEARCH database. In this model update, a more recent (2009) TRANSEARCH database was used to re-estimate trip generation equations for internal-external (IE) truck trips and external-internal (EI) trips.

The trip generation equations were developed through the estimation of linear regressions of the TRANSEARCH data and the population and NAICS employment on a zip code basis. The equations were developed at the zip code level because that is the common unit of geography for which the commodity, population, and NAICS employment data are available. The relationships established at the zip code level are then applied to the TAZ level data during the model implementation and validation stage.

The external model estimates the daily internal portion of IE/EI trucks produced and attracted by each Commodity Group to each TAZ in Phoenix, with the exception of special generators, based on the regression equations. The explanatory variables tested within the regression models included different employment categories and regional population.

4.1 Production Model

The production equations were fit to observed annual trucks for each of the nine commodity groups. Commodity group 4, nondurable manufacturing, and 6, printing, were combined due to a limitation in the NAICS codes available for printing as explanations for the productions. The production equations developed through a linear regression are shown in Table 4.1. The equation yields the annual trucks for each Phoenix TAZ based on the total NAICS employment type for that TAZ. The production equation is either a linear function of one variable listed or a multi-linear function of the two variables listed.

Table 4.1 Production Equations

Commodity Group					
Code	Name	Variable	coefficient	t-stats	r^2
1	Farm	NAICS 11	6.475	6.844	0.237
2	Mining	Natural log of NAICS 21	5,126.199	8.757	0.335
3	All Consumer Manufacturing	NAICS 31	6.182	11.907	0.647
		NAICS 33	0.417	6.348	
4&6	(Non-consumer) Nondurable Manufacturing Including Printing	NAICS 32	9.582	14.626	0.843
		NAICS 33	1.291	6.77	
5	(Non-consumer) Durable Manufacturing	NAICS 32	8.795	16.151	0.875
		NAICS 33	1.355	8.538	
7	Miscellaneous Freight	Total Employment	0.004	2.517	0.273
		NAICS 48	0.168	4.004	
8	Empty trucks	Sum of total truck attraction	0.881	235.025	0.997
9	Warehousing	NAICS 42	3.734	35.556	0.888

It should be noted that the TRANSEARCH database and commodity groups are based on the STCC classification system. Therefore, the NAICS employment categories do not fit perfectly into the commodity group types with similar names. For example, while the best regression for CG3 should be regressing with NAICS 31 (consumer manufacturing), the best regression for CG 4&6 should be regressing with NAICS 32 (non-durable manufacturing), and the best regression for CG 5 should be regressing with NAICS 33 (durable manufacturing). The CGs do not line-up exactly with the NAICS employment categories. Thus, we tested all three CG manufacturing groups and found the best regression of the NAICS 31-33 combination.

Mixed freight according to STCC for trucks is Scrap and Recyclable Paper and Metals, not mixed commodities in a single shipment. Thus, total employment as a regressor for CG 7 makes sense given the type of waste that is generated at each employment site. The STCC's warehousing is more similar to NAICS's wholesale trade than it is to NAICS's warehousing. Thus, NAICS 42 is the best regressor for the CG 9. Finally, the inclusion of commodities in the AZDOT TRANSEARCH used to develop the 2008 model was different than the MAG TRANSEARCH used to develop these regressions. Apparently the flows for Sand and Gravel, which would place them in the Mining CG, were not included in the AZDOT TRANSEARCH, but were included in the MAG TRANSEARCH.

The linear regression equations presented in Table 4.1 are fit to the data with assumed special generator zip codes removed from the data. Special generators were chosen based on running the regressions on the full dataset. Special generator zip codes were determined by identifying unusually high truck movements which are outliers to the fit of the truck movements against the explanatory variables(s) based on a manual visual inspection of the regression equations fit to the observed data. Not all outliers were chosen as special generators for a variety of reasons including: 1) having a bunch of outliers all clustered together; 2) outliers having fewer truck units compared to employment, and thus were under predicting rather than over predicting the number of trucks; 3) having an outlier just outside the acceptable distance from the regression line and tending to have other ZCTAs near it but inside the acceptable area.

Figures 4.1 to 4.8 graphically display the attraction regression equations fit to the observed data and the magnitude of the special generator values. The graphs presented show the final regression equation (with special generators removed) plotted with all records. The difference between the plotted final regression value and the actual number of trucks for the special generator gives the value that is used as the special generator. Plotting the special generators on the graph help us to understand visually where the special generator is in relation to the non-special generators and why it was chosen as a special generator.

Figure 4.1 Farm (Commodity Group 1) Production Regression and Special Generator Values

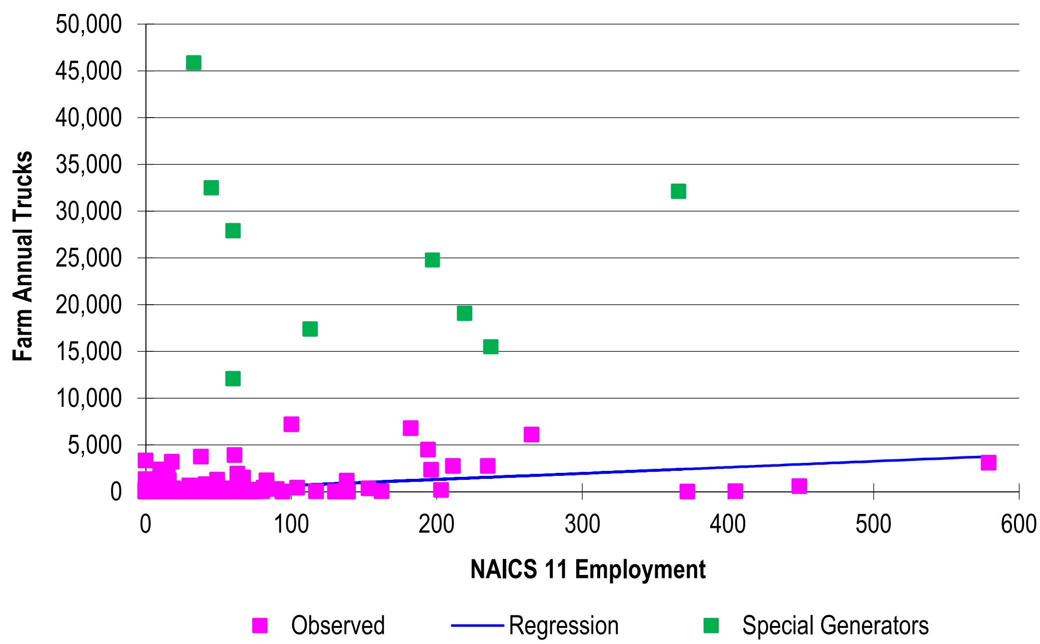


Figure 4.2 Mining (Commodity Group 2) Production Regression and Special Generator Values

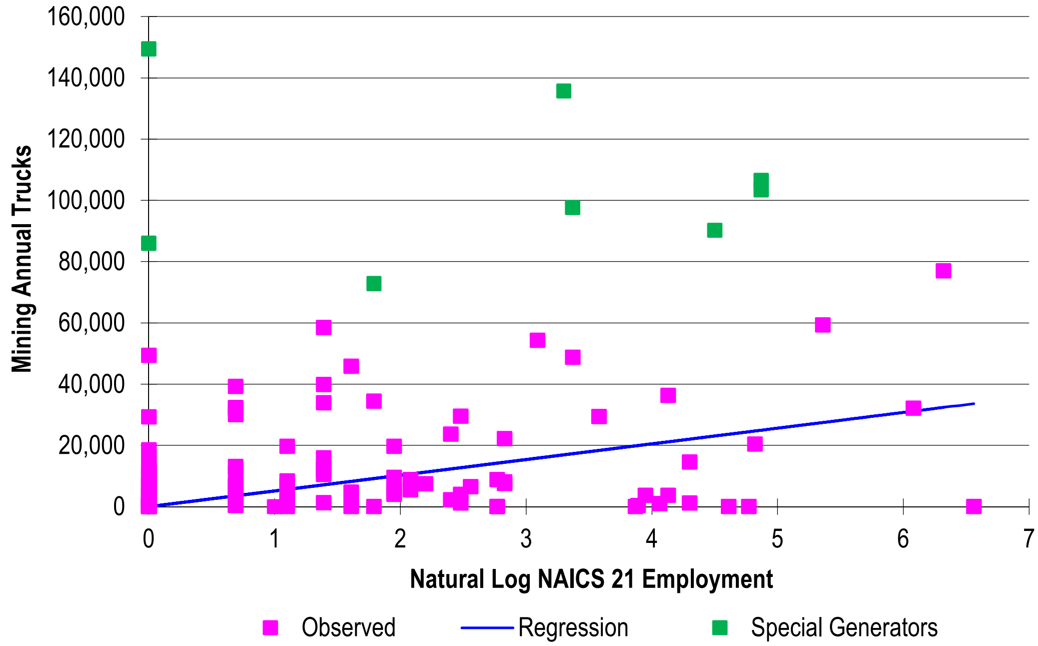


Figure 4.3 Consumer Manufacturing (Commodity Group 3) Production Regression and Special Generator Values

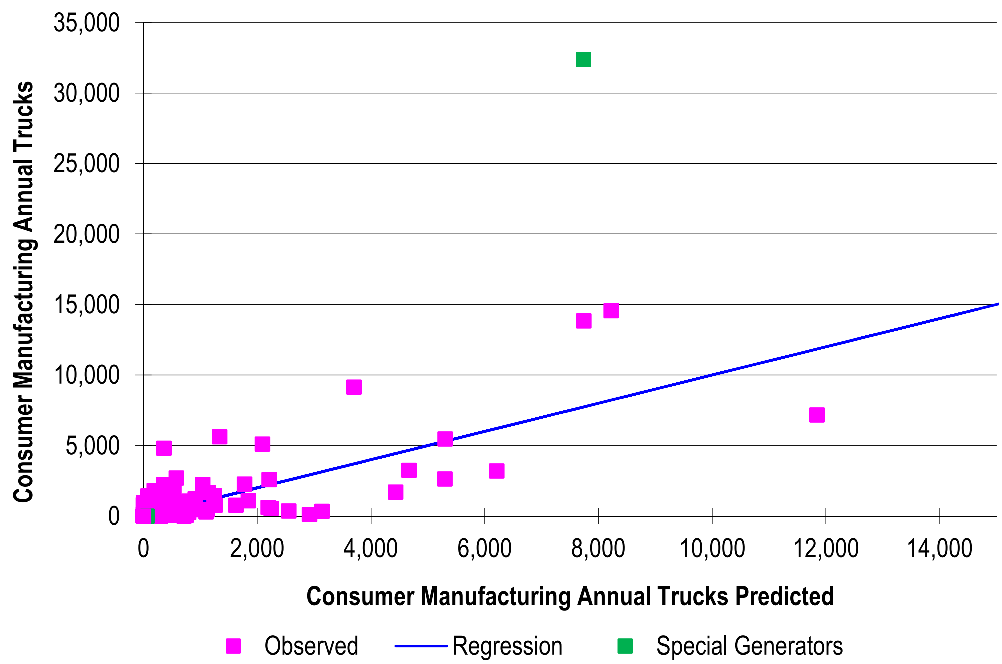


Figure 4.4 Nondurable Manufacturing (Commodity Group 4 and 6) Production Regression and Special Generator Values

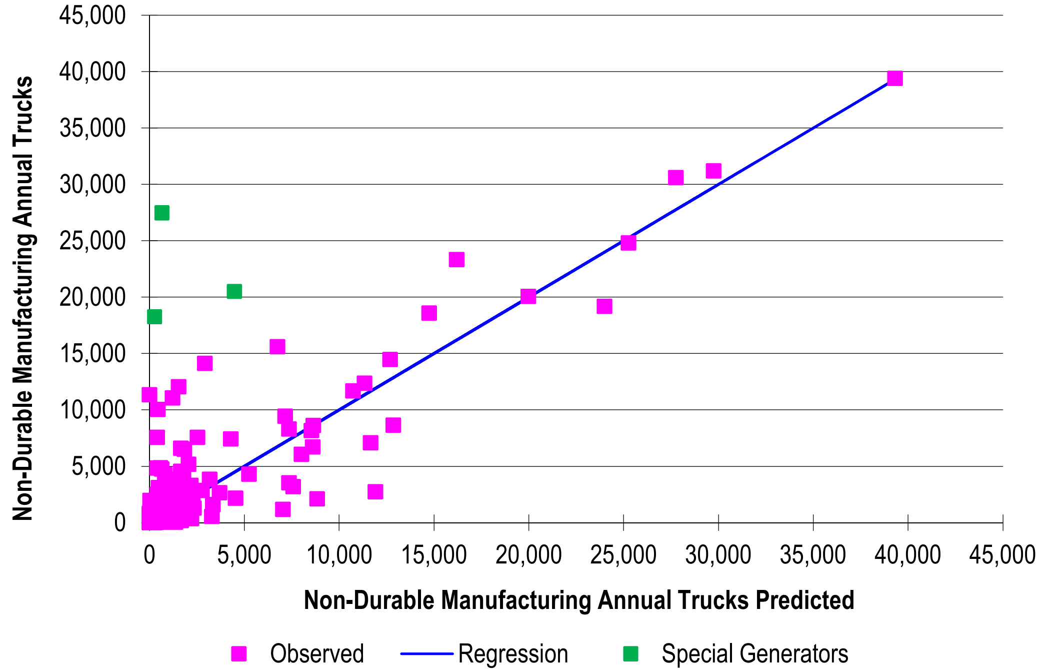


Figure 4.5 Durable Manufacturing (Commodity Group 5) Production Regression and Special Generator Values

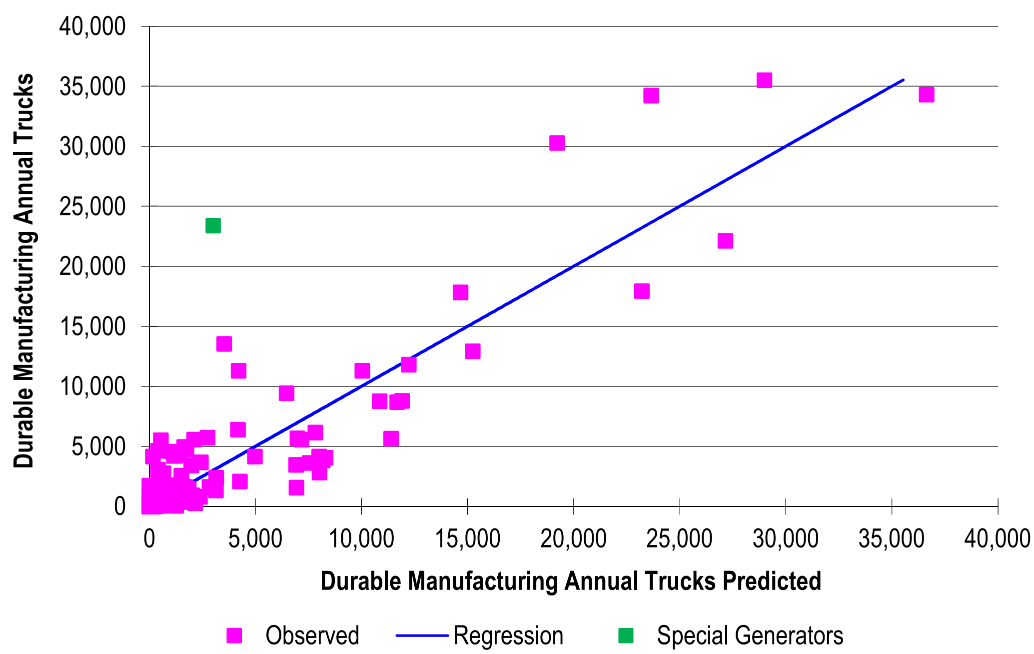


Figure 4.6 Miscellaneous Freight (Commodity Group 7) Production Regression and Special Generator Values

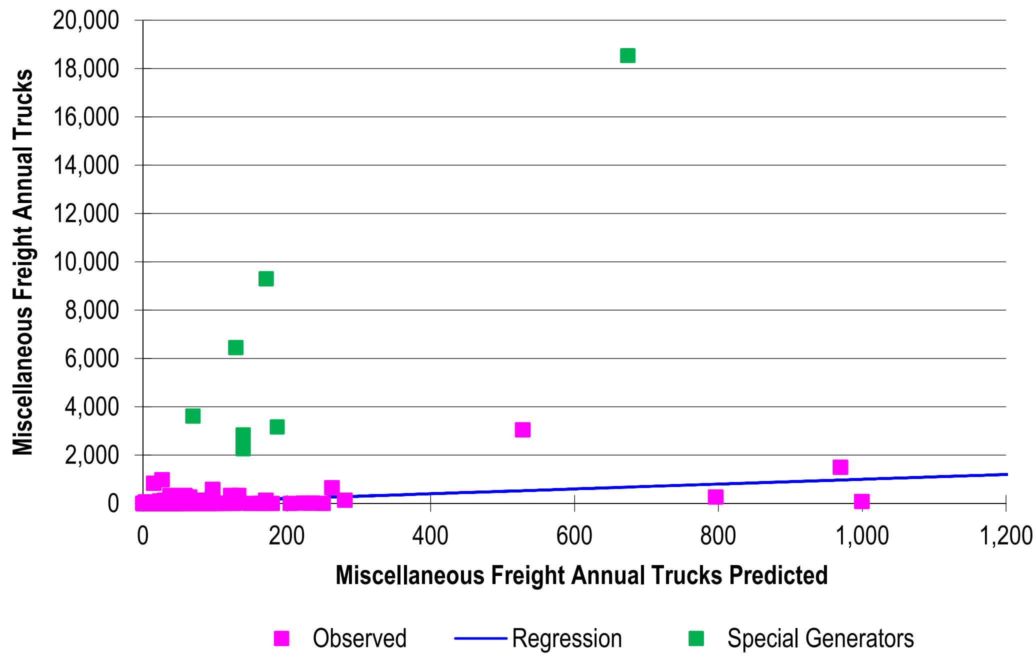


Figure 4.7 Empty Trucks (Commodity Group 8) Production Regression

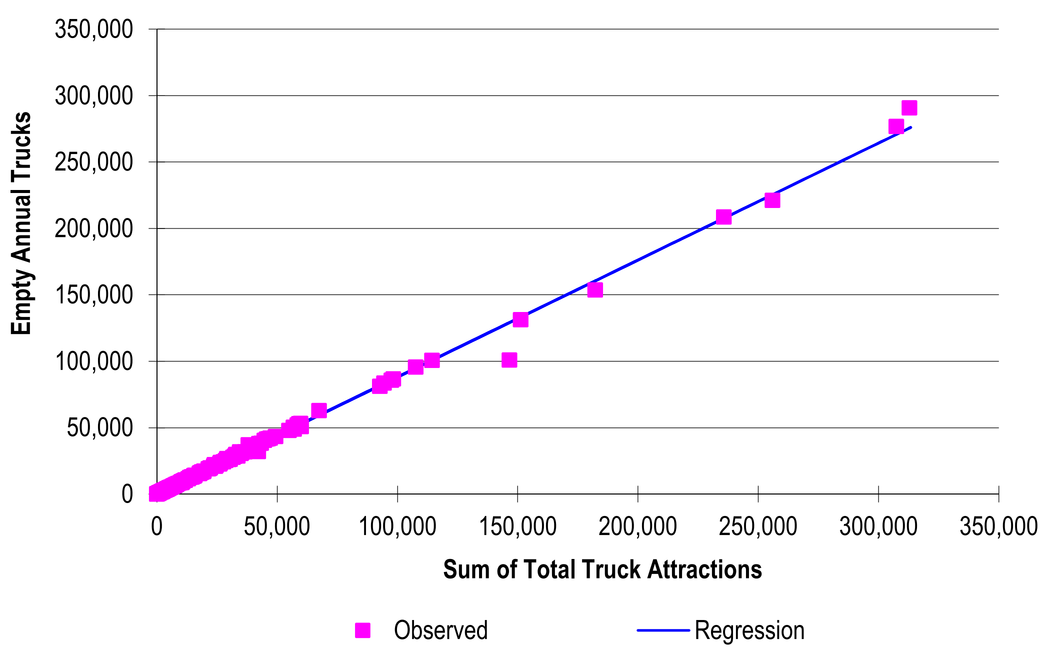
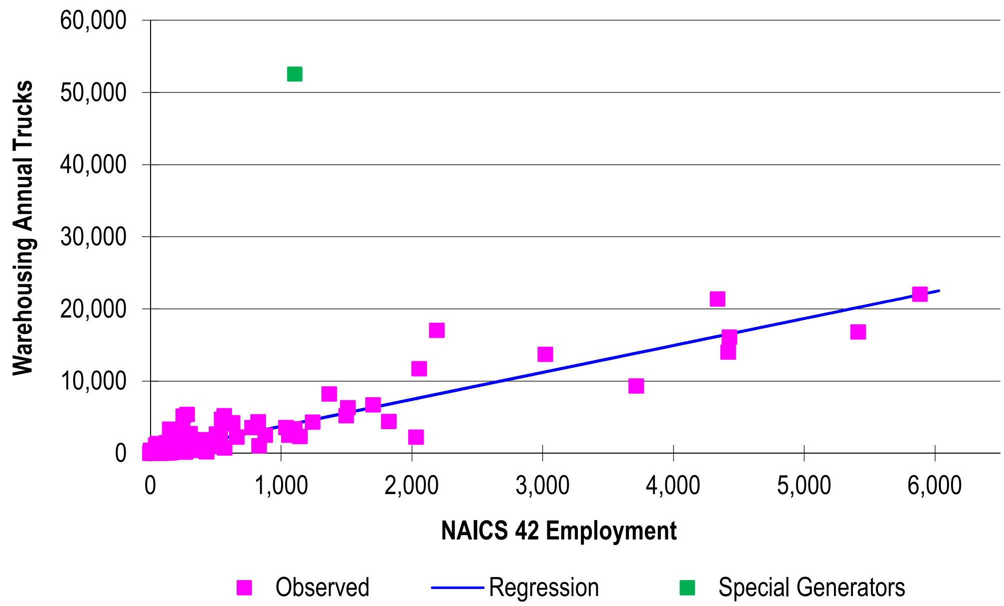


Figure 4.8 Warehousing (Commodity Group 9) Production Regression and Special Generator Values



4.2 Attraction Model

The attraction equations were fit to observed annual trucks for all nine Commodity Groups. Nondurable manufacturing (Commodity group 4) and printing (Commodity Group 6) were combined due to a limitation in the NAICS codes available for printing productions. The attraction equations are shown in Table 4.2. The attraction equation is either a linear function of one variable listed or a multi-linear function of the two variables listed.

The linear regression equations presented in Table 4.2 are fit to the data with special generator zip codes removed from the data. Similar to productions, special generators were chosen based on running the regressions on the full dataset. Figures 4.9 to 4.16 graphically display the attraction regression equations fit to the observed data and the magnitude of the special generator values. The graphs presented show the final regression equation (with special generators removed) plotted with all records. The difference between the plotted final regression value and the actual number of trucks for the special generator gives the value that is used as the special generator.

Table 4.2 Attraction Equations

Commodity Group					
Code	Name	Variable	coefficient	t-stats	r2
1	Farm	Total Population	0.001	2.02	0.025
2	Mining	NAICS 32	31.37	11.733	0.74
		NAICS 33	3.031	3.889	
3	All Consumer Manufacturing	NAICS 42	1.753	13.56	0.543
4 & 6	(Non-consumer) Nondurable Manufacturing including Printing	NAICS 42	2.946	14.236	0.565
5	(Non-consumer) Durable Manufacturing	NAICS 42	4.61	20.133	0.723
7	Miscellaneous Freight	NAICS 32	0.239	10.178	0.402
8	Empty trucks	Sum of total truck production	0.992	186.191	0.995
9	Warehousing	NAICS 42	2.905	9.921	0.387

Figure 4.9 Farm (Commodity Group 1) Attraction Regression and Special Generator Values

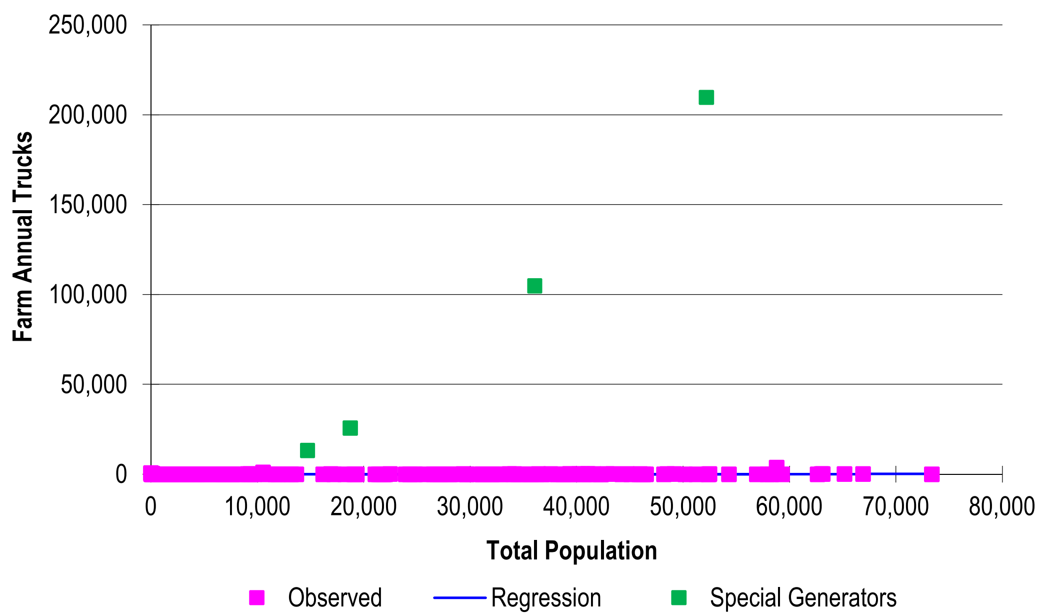


Figure 4.10 Mining (Commodity Group 2) Attraction Regression and Special Generator Values

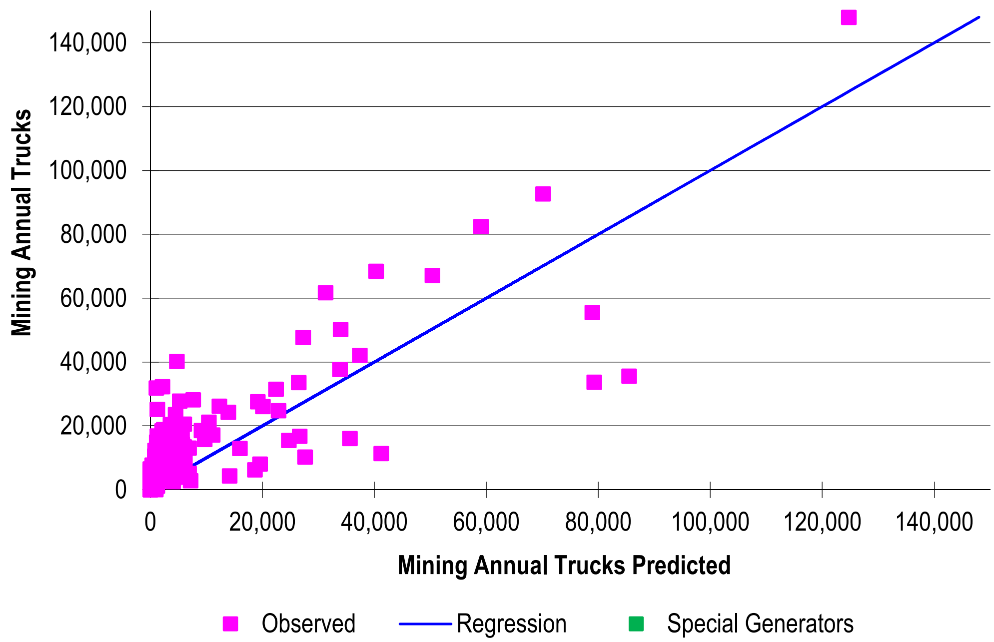


Figure 4.11 Consumer Manufacturing (Commodity Group 3) Attraction Regression

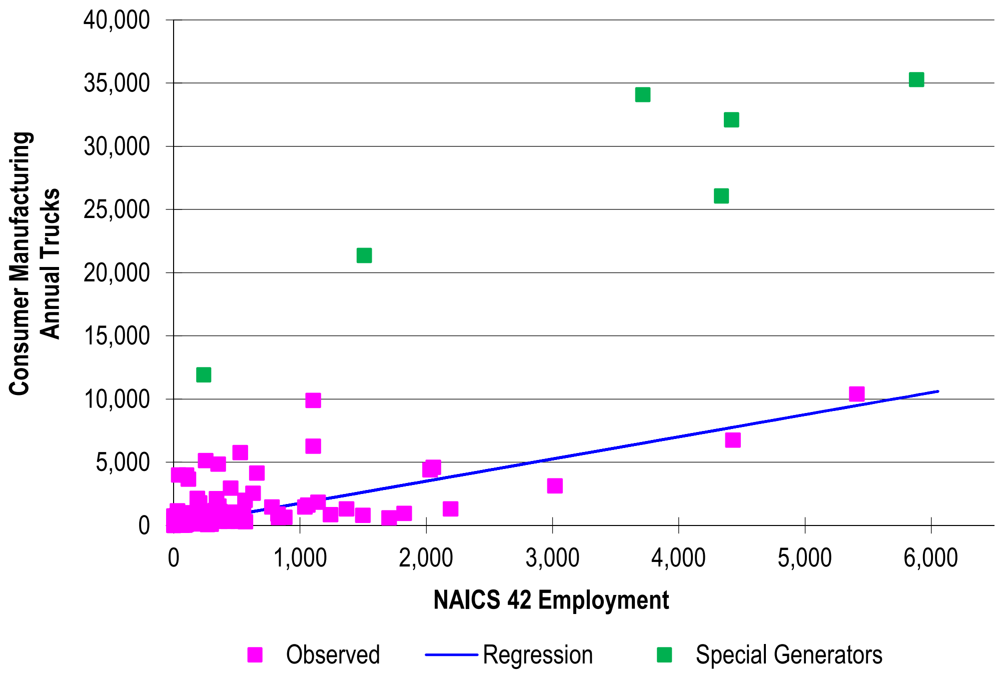


Figure 4.12 Nondurable Manufacturing (Commodity Group 4 and 6) Attraction Regression and Special Generator Values

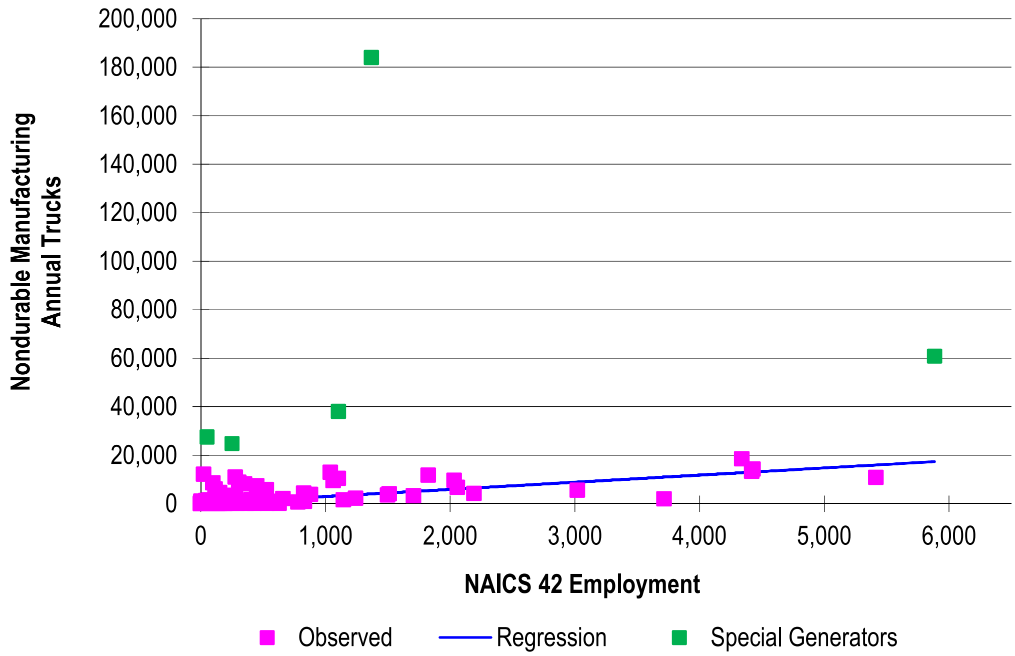


Figure 4.13 Durable Manufacturing (Commodity Group 5) Attraction Regression and Special Generator Values

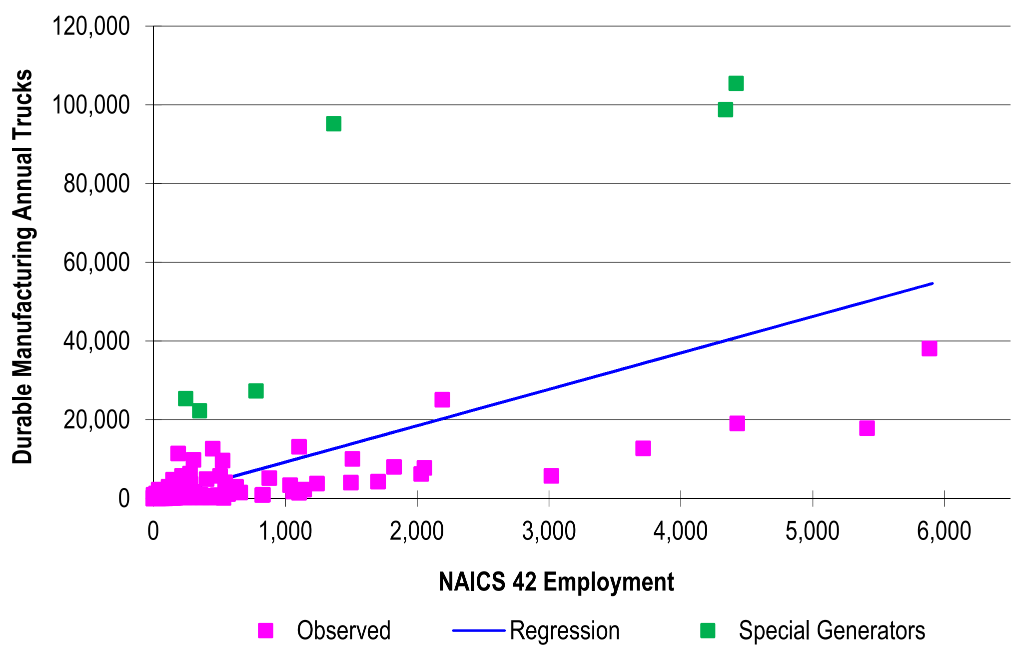


Figure 4.14 Miscellaneous Freight (Commodity Group 7) Attraction Regression

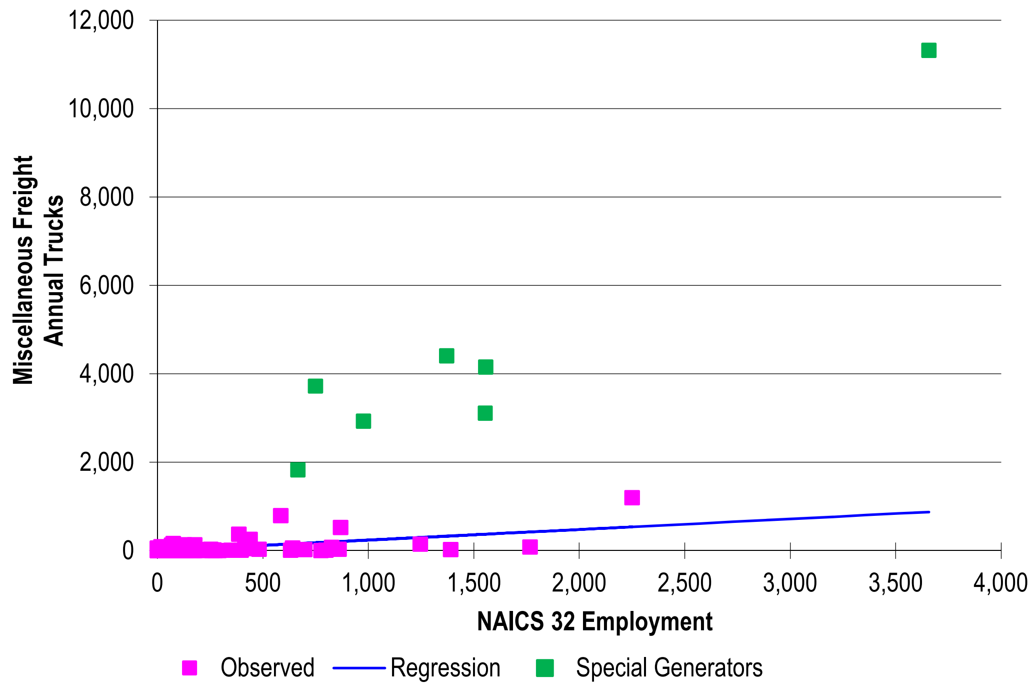


Figure 4.15 Empty Trucks (Commodity Group 8) Attraction Regression

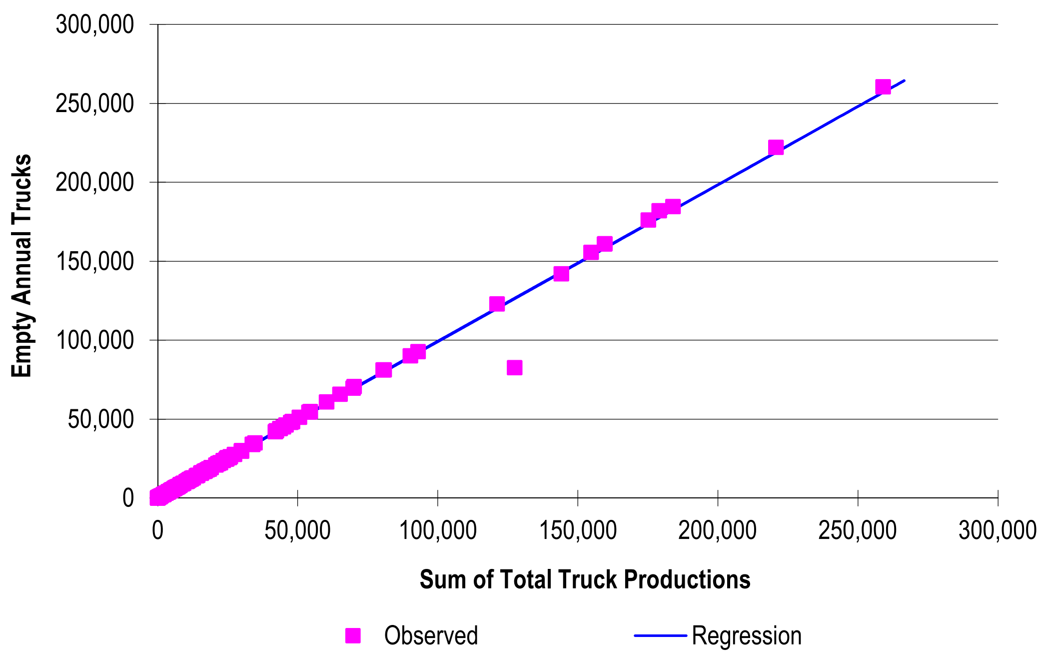
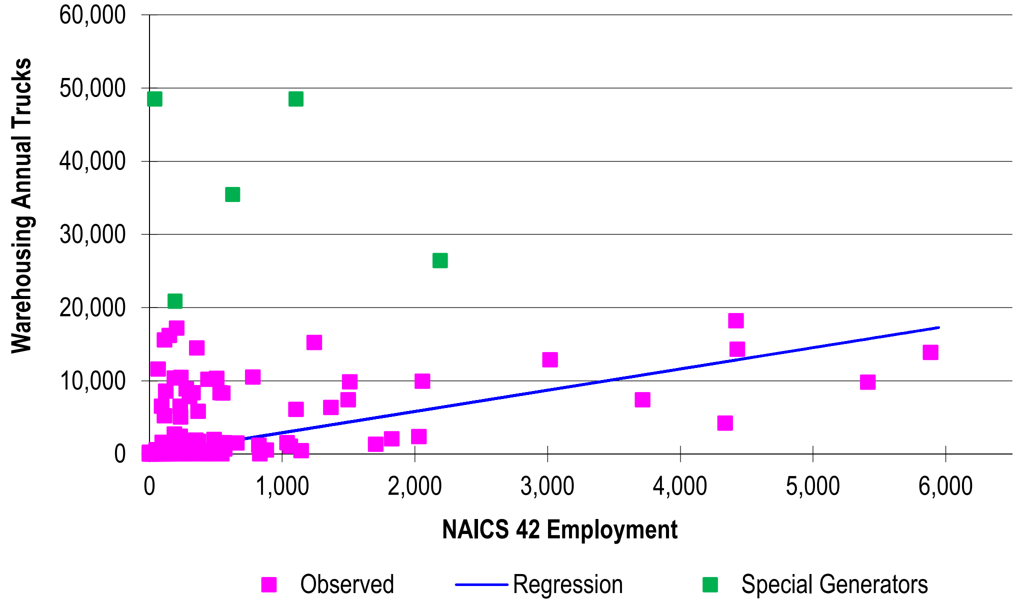


Figure 4.16 Warehousing (Commodity Group 9) Attraction Regression and Special Generator Values



4.3 External Trip Distribution

The external productions (IE) and attractions (EI) are distributed using average travel times as impedances in the external gravity model. The productions and attractions are controlled for at the external stations based on counts.

The average travel times from the internal MAG region to the external stations were derived from skimming the model to produce times from the 127 ZCTAs to 13 external stations. Using tonnage information at the ZCTA level, the travel times were weighted to produce EI and IE average times for the nine CGs as shown in Table 4.3. The coefficients for the friction factor computations are the reciprocals of these average travel times, also shown in this table.

Table 4.3 Average Travel Times from Internal ZCTAs to External Stations by Commodity Group

	CG1	CG2	CG3	CG4&5	CG6	CG7	CG8	CG9	CG10
IE AVG TT	62.78	51.12	67.79	68.25	65.12	61.69	72.87	60.93	64.58
EI AVG TT	65.12	50.22	61.08	63.56	66.14	69.56	71.38	66.77	69.40
IE (1/AVG)	0.0159	0.0196	0.0148	0.0147	0.0154	0.0162	0.0137	0.0164	0.0155
EI (1/AVG)	0.0154	0.0199	0.0164	0.0157	0.0151	0.0144	0.0140	0.0150	0.0144
AVG	0.0156	0.0197	0.0156	0.0152	0.0152	0.0153	0.0139	0.0157	0.0149

The gamma friction factor is expressed as the following function:

$f(x) = ax^{-b}e^{-cx}$

where,

a = 1;

b = 0.3;

c = 1/Average Trip Length (minutes)

The values of 'c' are shown in Table 4.2 as the reciprocals of the average travel times.

4.4 Splitting External Trucks into Medium and Heavy Trucks

The TRANSEARCH commodity flow database, which is the basis for the development of the external truck model, comprises of shipments that is predominantly made by FHWA Vehicle Classes 5-13. This is all medium (classes 5-7) and heavy (classes 8-13) trucks in the external truck model. There is however no distinction made in the TRANSEARCH database between medium and heavy trucks.

The 2010 external station counts were used to split the total external trucks into medium and heavy by external station. The counts were available by axle that made it easier to classify them into the FHWA 13 classes. These were also compiled by direction – NB/EB and SB/WB – which were averaged to get one set of percentages for each of the 13 external stations for medium and heavy trucks. These percentages are shown in Table 4.4.

While these percentages are the source for the splits of total trucks into medium and heavy trucks at external stations, the splitting actually needs to be applied at the individual cell level or every O-D pair. So a set of factors were developed for medium and heavy trucks when the previous external truck model was first developed in 2009/2010. These factors are a byproduct of TransCAD's Frataring process called the Iterative Proportional Fitting (IPF), where the percentage split of medium and heavy trucks are the control totals or constraints at the external end. These factors, termed as "dummy factors" in the model stream, are required only for those cells that are actually distributed, that is, I-E and E-I cells. In this model update, the percentages shown in Table 4.4 are used in the IPF procedure, and the dummy factor matrix was updated to the new base year.

Table 4.4 Percentage of Medium and Heavy Trucks at the External Stations

MAG Route Name	External MAG Station	Percent of Medium Trucks	Percent of Heavy Trucks
SR 85 South	1	52%	48%
I-10 Fwy	2	19%	81%
SR 77 N	3	44%	56%
SR 77 S	4	52%	48%
U.S. 60 East Hwy	5	51%	49%
SR 188	6	51%	49%
SR 87 North	7	42%	58%
I-17 Fwy	8	23%	77%
SR 89 North	9	65%	35%
U.S. 93 North	10	18%	82%
U.S. 60 West Hwy	11	36%	64%
I-10 Fwy	12	6%	94%
I-8 Fwy	13	20%	80%

4.5 Special Generators

The special generator values were calculated as the difference between the actual truck units (from TRANSEARCH) and the estimated truck units from the regression equation. As explained earlier in this chapter, the special generator ZCTAs were identified by visual examination of the regression charts, and all the green dots are classified as special generators. These are outliers that cannot be explained well by the estimated regression equations. This way, the model will estimate, based on employment in the TAZ, the number of truck units attracted/produced in the zone, and then add on the additional number of trucks that are independent of employment. It is noted that the reported truck units from TRANSEARCH are for 2009 and the estimated truck units are based on 2010 NAICS2 employment, and thus the special generators are 2010 estimated values. The reported values in Table 4.5 contain the special generator annual truck values for each zip code and commodity group and are considered to be for the base year of 2010 because no reported values are available for 2010.

Separately, an examination of the potential special generators in each TAZ is being pursued. Using the Bureau of Transportation Statistics GeoFreight database, the point location of freight terminals is being identified by the TAZ in which they are located. Using the correspondence table of ZCTAs to TAZ, that information is used to assign the special generator totals by ZCTA in Table 4.5 to the appropriate TAZ. The special generator values, adjusted from annual to average weekday trucks, is added to each corresponding TAZ for each commodity group after the regression equations are applied.

Table 4.5 Special Generator Annual Trucks by Zip Code and Commodity Group for Productions and Attractions

	Production CG								Attraction CG							
ZCTA	1	2	3	4&6	5	7	8	9	1	2	3	4&6	5	7	8	9
85003													19,038			
85007						2,702			13,192					1,668		
85008		149,493										180,001	82,548			
85009	32,198	80,385				17,865					24,961	43,509		10,445		
85027		78,466														
85034														3,784		
85040		67,150									24,359		64,583	4,080		
85041						3,546										
85043		85,966									18,463		58,667			
85044																33,634
85085																20,322
85119		63,617		17,999												
85122				16,036												
85131																48,381
85138	29,756															
85139	23,492								25,635							
85147	16,650															
85172	13,953															
85193	27,504			26,826												
85210						2,977										
85212					20,390								23,126			

ZCTA	Production CG								Attraction CG							
	1	2	3	4&6	5	7	8	9	1	2	3	4&6	5	7	8	9
85225						6,327								3,544		
85226																20,074
85254													20,121			
85258						2,120										
85260		81,494														
85281	11,700	118,805												2,738		
85282	45,657		24,644								27,573					
85301						9,127		48,421				34,786		2,699		45,298
85303												24,061				
85323											11,505					
85326									209,585							
85339									104,778							
85353	17,644										18,708					
85373												27,364				

The special generator truck trips were available at Zip Code Tabulation Area (ZCTA) level. The MAG model requires the special generator trips to be at the model TAZ level. In order to satisfy this requirement, the geographic association between the TAZ boundary and the ZCTA boundary was developed. The MAG TAZ shapefile was coded with ZCTA code. The point shape file representing the freight terminals was used to highlight the TAZs that contain special generators within each of the ZCTAs listed in the special generator trip tables. Then, the special generator trips at the ZCTA level were equally distributed among the highlighted TAZs. The ZCTA level trips were equally distributed since no information was available to determine the weights of the special generator TAZs in generating special generator trips.

In order to make the association between special generator TAZs and ZCTA codes, the TAZ shape file and the freight terminals point shape file were opened in TransCAD. In the TAZ layer, the TAZs included within the ZCTA listed in the special generator trip table was highlighted (Figure 4.17). The special generator TAZs were identified from the location of the freight terminals within the ZCTA boundary (Figure 4.18). Then, the special generator trips generated by the TAZs are calculated by dividing the number of highlighted TAZs.

Figure 4.17 The heighted TAZs in ZCTA

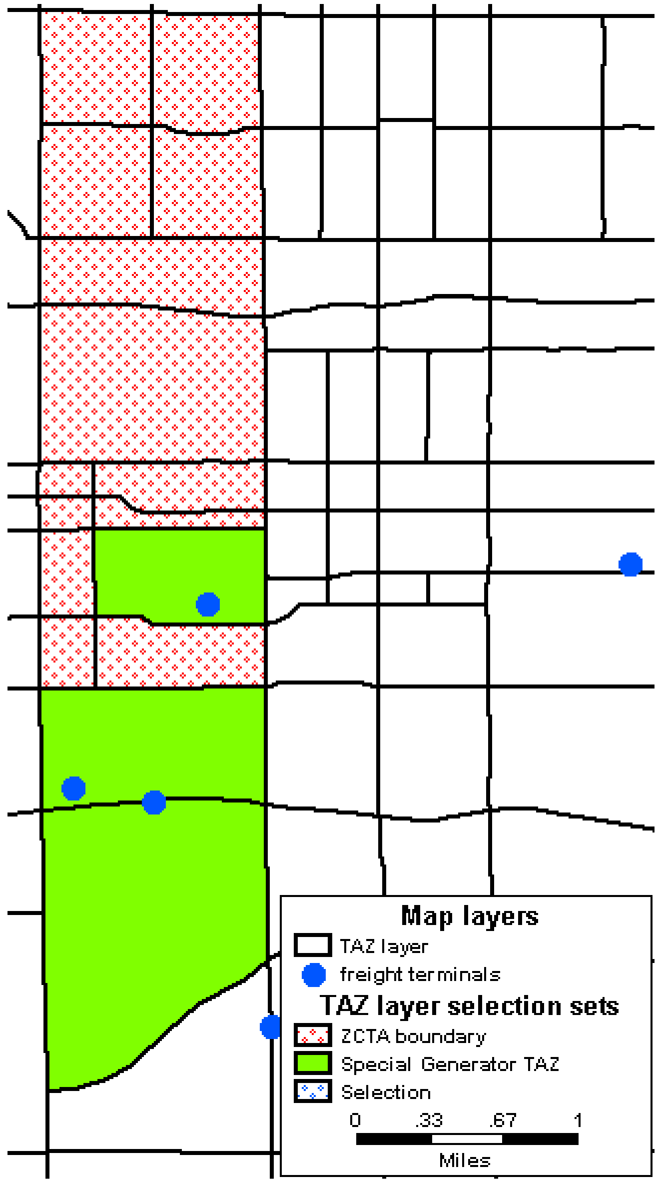
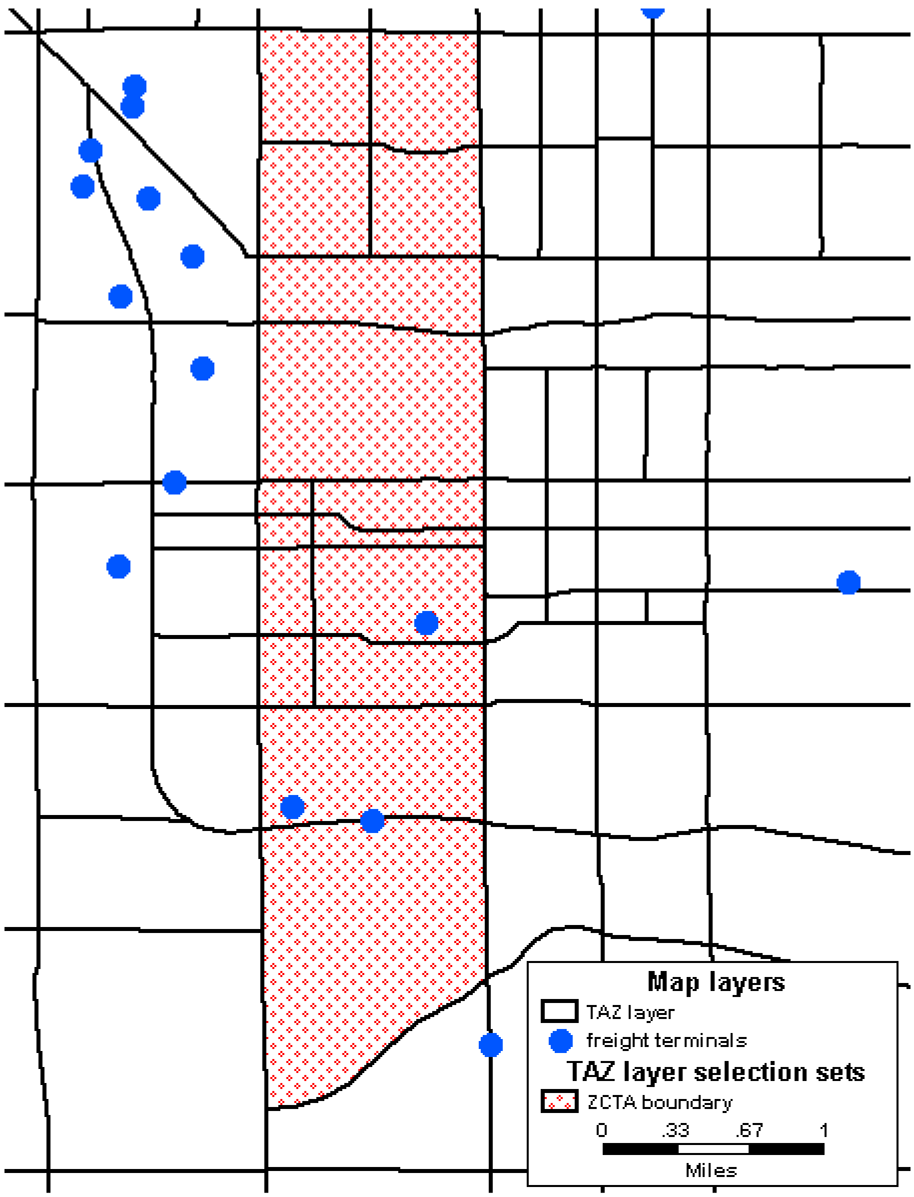


Figure 4.18 The special generator TAZs



4.6 DEVELOPING E-E TRUCK TRIP TABLE

The E-E trucks are derived from the TRANSEARCH database as most of the E-E freight flow tonnages that pass through the MAG region are pre-dominantly heavy trucks. The TRANSEARCH database has counties as zones within its "purchased" area and state portion of Bureau of Economic Analysis Economic Areas (BEA) outside of the "purchased" area. The most active zone with respect to freight was identified for each of these "BEA" zones. The counties within the MAG TRANSEARCH "purchased" area were associated directly with the FAF network zones. An assignment was preformed of this truck trip table on the FAF3 national highway network. A boundary was drawn on the FAF3 network to identify those links that cross the MAG boundary. TransCAD's "Subarea analysis module" was used to convert the national TRANSEARCH truck trip table into one that had Maricopa and Pinal Counties within the MAG region and the 13 external stations associated with the MAG model region. The TRANSEARCH trips to the portions of Yavapai and Gila Counties that are inside the MAG model region could not be separated from those that were inside the MAG model region. The resulting External station flows were to be factored to actual truck counts, thus the exclusion of the portions of the MAG 2009 TRANSEARCH truck table that should be associated with the small portions of these counties inside the MAG model region was excluded from the development of the seed table, but was included after the factoring to observed truck counts. This process resulted in the seed commodity truck flow table. The associations of the FAF3 highway network links and the MAG external stations are shown in Table 4.6. While links in the FAF3 highway network included S88, N15 and S177 as shown in Table 4.6, these links were not assigned any flows by TransCAD, and these links are also not MAG external stations. While the processing will combine Pinal and Maricopa, they are shown separately in the subarea windowed trip table from MAG 2009 TRANSEARCH as shown in Table 4.7.

Table 4.6 MAG External Stations and FAF Highway Network Crossing the MAG Boundary

MAG External Station Number	MAG External Station Name	Official MAG Names	FAF Highway Link (or Zone)
0	S88 in Maricopa		101486
0	N15 in Pinal		102462
0	S177 in Pinal		103373
1	S85 in Pinal	SR 85 South	102472
2	I10 in Pinal	I-10 Fwy	102477
3	S77 in Pinal	SR 77	103377
4	S77 in Pinal	SR 77	103082
5	U60 in Pinal	U.S. 60 East Hwy	103379
6	S188 in Maricopa	SR 188	121769
7	S87 in Maricopa	SR 87 North	121654
8	I17 in Maricopa	I-17 Fwy	121655
9	S89 in Maricopa	SR 89 North	121612
10	U93 in Maricopa	U.S. 93 North	121610
11	U60 in Maricopa	U.S. 60 West Hwy	120322
12	I10 in Maricopa	I-10 Fwy	101488
13	I8 in Maricopa	I-8 Fwy	101599
Maricopa			(4013)
Pinal			(4021)

Table 4.7 MAG 2009 TRANSEARCH Daily Trucks Assigned to FAF Highway Network and Windowed to MAG Model Region

		D Ext Station															
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Maricopa**	**Pinal**	**Grand Total**
O Ext Station	1																
	2							38	60				915	2,384	1,367	506	5,268
	3																
	4																
	5							18									18
	6																
	7		16			19			14				9	3	125	52	237
	8		42					8					60	19	1,738	39	1,905
	9														37	0	37
	10																
	11																
	12		893					37	92						2,406	77	3,505
	13		1,411					5	99						428	212	2,155
	Maricopa		927					123	1,160				1,625	537		1,335	5,707
	Pinal		652					24	52				31	150	1,176		2,086
	Total		**3,941**			**19**		**253**	**1,477**				**2,639**	**3,093**	**7,277**	**2,220**	**20,919**

Also in Table 4.7, no TRANSEARCH flows were assigned for the following MAG external stations: 1 – S85 in Pinal, 3 – S77 in Pinal, 4 – S77 in Pinal, 6 – S188 in Maricopa, and 10 – S71 in Maricopa. The intent in developing the windowed TRANSEARCH Table was to develop by a Fratared trip table to match observed counts. So that flows must be allowed in these and other cells. Flows with zeros, for missing stations or origin destination pairs that were not otherwise assigned, will be given a value of 0.0001.

Fratar Process

1. As noted above a value of 0.0001 was inserted into every zero cell in Table 4.7. This step of inserting nonzero flows is necessary because the Fratar process will always produce a zero value if the initial value is zero. The multiplication of 0.0001 ensures a non-zero initial value, but will not otherwise bias the flow towards that cell. Since the Fratar process is invariant to uniform scaling, the initial value will not prevent producing the target amount.

2. The target daily truck flow for the Fratar process is established from the MAG supplied external station counts shown in Table 4.7. The target assumes that 50 percent of the daily truck count is in each direction.

3. The Fratar process in travel demand modeling packages such as TransCAD require that a constraint, or target, be set for every row and column. It was not the intent that the flows to the internal zones which were served by the flows to and from internal zones such as those in Maricopa and Pinal Counties, would be constrained since they by definition have no observed truck counts. Therefore, a special program was written to apply the Fratar process without constraining the internal productions and attractions.

   The implementation of the Fratar process within TransCAD would require that there be a constraint on every origin row and destination column. Those constraints in this case would be the traffic counts at the external stations. For this application, traffic counts at external stations can travel to or from internal TAZs or other external stations. For this reason, it is desirable to adjust the internal TAZs trip ends during the Fratar factoring process (also known as Iterative Proportional Fitting). However it is meaningless to have a constraint for the internal TAZs, which can be treated as the summary over all internal TAZs, especially for TAZ to TAZ trips which cannot be observed by traffic counts. Therefore a program was developed to implement the Fratar process using the seed TRANSEARCH matrix with traffic count constraints on each external station, but no constraint on the sum of trips in the origin row or destination columns of the internal TAZs. The Fratar process operates iteratively, first on the origin rows and then on the destination columns. In this process, the TAZs as origin are adjusted, and these adjustments are unconstrained for the column or row total over all TAZs, but are constrained to observed counts for the external stations. This

Fratar process was executed for 1,000 iterations and achieved closure criteria of SSE of marginals vs. targets in the final matrix is on the order of 10^{-25}. It is not necessary that this software be part of the MAG truck model. This process is a work step that is only required when the seed TRANSEARCH matrix is calibrated to observed traffic counts for the base year.

4. For the updated table of total trucks, each new Tij was divided by the original Tij to produce a factor. This factor for each ij pair was applied to each of the appropriate ij cells in the original multi-commodity file. This produces an updated commodity table. The Internal Trip ends will be established through a regression of employment versus TRANSEARCH observations as described in another Technical Memorandum. The Fratared totals from each external station origin to the internal zones will be the balanced total of external production to be used in Trip Distribution. The Fratared totals from each external station destination from the internal zones was the balanced total of external attractions to be used in Trip Distribution. The EE portion of the updated table (total of all commodities) was saved as that portion of the base OD table.

As described above, the internal truck trip ends were developed through a regression of truck trip ends by commodity group against NAICS2 employment. The results of the Fratar process established the external trip ends for the IE and EI distribution of truck trips. Additionally, the Fratar process provides the only source of information the External- External portion of the truck trip table. Those values are shown in Table 4.9. The External-External portion of the truck trip table is shown in Table 4.10.

Table 4.8 MAG External Station Truck Volumes

MAG Route Name	External MAG Station	MAG External Daily Truck Counts
SR 85 South	1	78
I-10 Fwy	2	12,320
SR 77	3	910
SR 77	4	246
U.S. 60 East Hwy	5	1531
SR 188	6	153
SR 87 North	7	1431
I-17 Fwy	8	5,069
SR 89 North	9	224
U.S. 93 North	10	1671
U.S. 60 West Hwy	11	232
I-10 Fwy	12	9,619
I-8 Fwy	13	2,464

Table 4.9 External-Internal /Internal External Truck Trip Ends – "Fratar"ed Results

MAG Route Name	External MAG Station	External Internal Productions	Internal External Attractions
SR 85 South	1	0	0
I-10 Fwy	2	2,785	3,141
SR 77	3	2	4
SR 77	4	1	1
U.S. 60 East Hwy	5	2	2
SR 188	6	0	1
SR 87 North	7	178	173
I-17 Fwy	8	2,265	2,102
SR 89 North	9	71	1
U.S. 93 North	10	8	12
U.S. 60 West Hwy	11	1	1
I-10 Fwy	12	2,663	2,557
I-8 Fwy	13	216	198

Table 4.10 External-External Truck Table – "Fratar"ed Results

MAG ID	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
1	–	–	6	1	4	1	–	–	1	22	1	–	–	36
2	–	–	5	1	4	1	67	154	1	19	1	2,100	1,022	3,375
3	6	5	–	20	58	12	3	4	18	302	19	4	1	452
4	1	1	20	–	14	3	1	1	4	71	5	1	–	122
5	5	4	66	16	–	10	399	3	14	230	15	3	1	766
6	1	1	12	3	8	–	–	1	3	43	3	1	–	76
7		31	4	1	450	1	–	24	1	12	1	13	1	539
8		107	5	1	3	1	11	–	1	16	1	117	7	270
9		–	7	2	5	1	–	–	–	24	2	–	–	41
10	22	17	302	71	202	43	10	15	63	–	67	13	2	827
11	1	1	19	5	13	3	1	1	4	67	–	1		116
12		1,904	4	1	3	1	47	172	1	13	1	–		2,147
13		948	1	–	1	–	2	58	-	4		–	–	1,014
Total	**36**	**3,019**	**451**	**122**	**765**	**77**	**541**	**433**	**111**	**823**	**116**	**2,253**	**1,034**	**9,781**

5.0 Truck GPS Data

This chapter provides a description of third-party truck GPS data that was acquired and processed for use in the internal truck model development. In addition to describing the GPS data, this chapter also details the processing steps undertaken to create a truck trip and tour database.

5.1 GPS Devices in Trucks

The information that is used to support the development of truck trip distribution and touring models traditionally comes from truck trip diaries. These truck trip diaries are difficult to deploy and collect, generally do not support large volumes of data, and are very expensive. Therefore, MAG was determined to try other alternate methods of data collection or acquisition such as the GPS data. GPS devices are widely deployed in cell phones, autos, and trucks. These devices can display information about the position of the vehicle, often on a map of the area, and the desired destination, based on signals received from Global Positioning Satellites. Sometimes these devices not only receive the GPS satellite signals or other information, such as traffic conditions, they also may wirelessly transmit that information back to a central location.

There are a variety of reasons why truck GPS information is collected. The information may be an Automatic Vehicle Location (AVL) system to provide information to locate, for security reasons, the vehicle, driver and/or cargo, or to provide navigational or dispatch information. The GPS transmitter may be tied to the engine bus or other vehicle equipment as part of an Events Activated Tracking System (EATS). The event triggering a GPS transmission may be a condition of the engine (e.g., a specific temperature), a vehicle event (e.g., hard braking, or vehicle speed), or a request by the central office (e.g., a ping). Deploying a GPS transmitter and a central receiver may also be part of a Fleet Telematics System (FTS). Thus the purpose of GPS devices may be varied, such as: operational – to track and schedule the movement of vehicle, drivers or cargo; or maintenance – to track the condition and operation of the vehicle.

The GPS event information is collected to serve the business purposes of the truck fleet operators. Those businesses are under no obligation to share this information with others. In fact this information, since it contains sensitive information about the business practices of truck fleet operations, is contractually protected when it is collected as a part of subscription but provided to third parties. However, information pertaining to the GPS locations (in the form of latitude and longitude) and the time stamp at which the transmission was sent is available. This information can be processed to derive a truck trip or tour database that can be used for model estimation.

5.2 ATRI GPS DATA FOR MAG

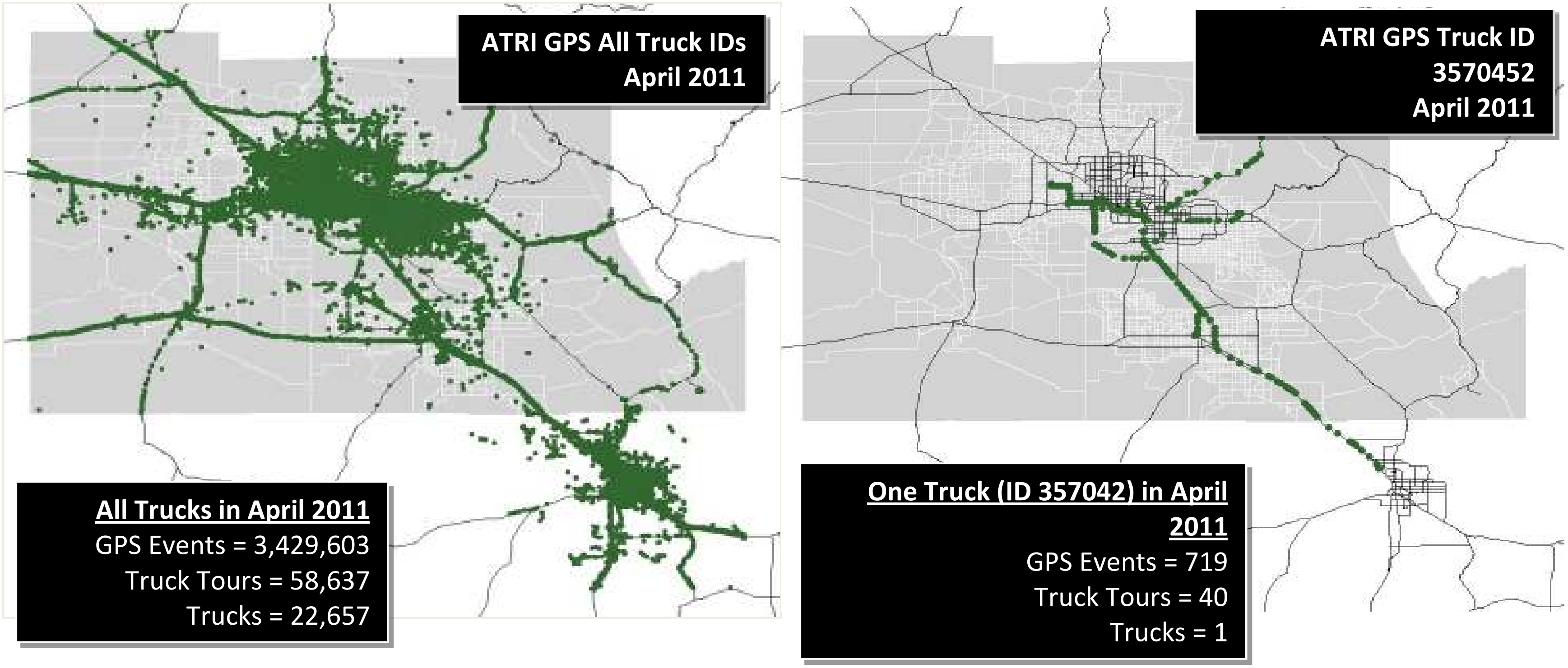
CS successfully processed the ATRI data for the Los Angeles MPO as part of a regional goods movement project[4]. CS also acquired and processed data from other vendors such as Trimble and Calmar as part of the Los Angeles project. The Trimble data was used for updating the light-heavy and medium-heavy duty trucks while Calmar and ATRI were used to develop the heavy-heavy duty truck trip rates. For an NCFRP project, CS purchased Trimble data for four metropolitan regions namely Phoenix, Chicago, Baltimore and Los Angeles, and examined trip chaining patterns of trucks, nature of truck tours, number of stops, average impedance between stops and the nature of land use at each stop on tour.[5] CS, through a MAG contract, purchased the ATRI data for the MAG modeling area for the period from April 1, 2011 to April 30, 2011. The raw data delivery from ATRI contained 3,429,603 GPS event records. The locations of these GPS records are shown in Figure 5.1. There are GPS event records reported for 22,657 trucks that indulge in 58,637 tours. At these GPS events, the vehicle may be stopped or moving. In principle, only certain stopped records can be grouped into tours or trips, but tours or trips cannot be precisely computed without further processing.

Figure 5.1 also shows GPS records for one random truck for the whole month of April 2011. There are 719 records for this truck, which makes 40 tours in April 2011. A "tour" is defined as a sequence of GPS events for a given truck, where the event after last event is a change of date and a change in time of more than 2 hours. This time check is to allow for tours that extend past midnight. This definition of a "tour' is only intended to be used in the initial filtering of the GPS records. Subsequent processing was done to determine truck tours consistent with its use in the development of touring models.

[4] Cambridge Systematics, Inc., SCAG Task 4 Data Verification and Analysis, Technical Memorandum, October 2010.

[5] Cambridge Systematics, Inc., Freight-Demand Modeling to Support Public-Sector Decision-making, NCFRP Report 8, 2010.

Figure 5.1 All ATRI MAG GPS Truck Events During April 2011



The GPS event records for one random tour on April 1, 2011 for this truck is shown in Table 5.1. This table shows the 'primary anonymized data', which is the raw data as obtained directly from ATRI, as well as the 'processed data. The processing was conducted to determine the condition that can be associated with each GPS event. For each event, the time and position of the truck is computed. The Great Circle Distance (e.g., air miles) between the GPS events is calculated based on a comparison of the latitudes and longitudes of the events. The time between the preceding and following events is calculated based on the timestamp of those events. The "air speed" in MPH is calculated based on the distance from the last (…or to the next) GPS event divided by the time from the last (…or to the next) GPS event. It is from this comparison of the sequence of time, distances and speeds that a determination was made as to the action of the truck at that event. It should also be noted that the imprecision of the GPS location reading may erroneously give the indication that the truck has moved when the GPS location readings vary very slightly. This is due to the fact that the truck is making incidental movements within the same trip end (e.g., moving from a holding location to a loading dock), and those incidental movements are a continuation of the full stop that had already been determined. It is for this reason that the criteria for motion with respect to the last or next events is a speed of 5 MPH and not absolute zero. These events are also depicted on the left hand side in Figure 5.2.

The types of GPS events presented in Table 5.1 are defined as follows:

- **First Starting** –The first GPS event record in a tour whose "air speed" to the next GPS event is greater than 5 MPH. This indicates that the truck has just started to make a trip. This is a transitional event as the status of the truck is about change from a full stop to full motion.
- **Moving** – If the speed of the preceding GPS event and the next GPS event is more than 5 MPH, it is a "moving" event. That is, the truck is in full motion and is on its way to making a trip.
- **Stopping –** The "air speed" from the last event is greater than 5 MPH and the "air speed" to the next event is less than 5 MPH. This indicates that the truck is slowing down to make a stop. This is also a transitional event as the status of the truck is about change from full motion to a full stop.
- **Stopped** – This is not the last stop on a tour, and the "air speed" to the last event and to the next event is less than 5 MPH. This indicates that the truck has stopped and will be at that location for a certain duration of time.
- **Starting** – This record occurs after a 'stopped' event type when the "air speed" from the last event is less than 5 MPH and to the next GPS event is greater than 5 MPH. This indicates that the truck is in motion again and is traveling to the next stop on the tour.
- **Last Stopped** – The last GPS event record in a tour where the "air speed" from the last GPS event and to the next event is less than 5 MPH. This event

type is used for illustrative purposes only, and it does not functionally differ from the "stopped" event type.

Using these criteria for the GPS events shown in Table 5.1, it was possible to determine that only the transitional events where the truck is reported as starting (or entering) and stopping (or exiting) define truck trip ends (shown in red in Table 5.1). Between these transitional events, the truck may either be moving or stopped. The 'moving' and 'stopped' records add no information about those calculated trip ends, and were deleted from the GPS database. Only the transitional events are useful in determining the trip ends and have impacts on calculating truck trips and tours.

As shown in Table 5.1, there are four trip ends from this truck tour, which results from six GPS transitional events. Since the truck is returning back to its home base, there are actually only three trip ends or three trips resulting from three legitimate stops. The real truck tour for this particular truck, after the data has been processed, is shown in Figure 5.2, on the right hand side. The GPS coordinates of these trip ends were then geographically joined to shapefiles of TAZ boundaries and Land Use boundaries, and the appropriate TAZs and land uses of the three stops were identified as shown in Figure 5.2.

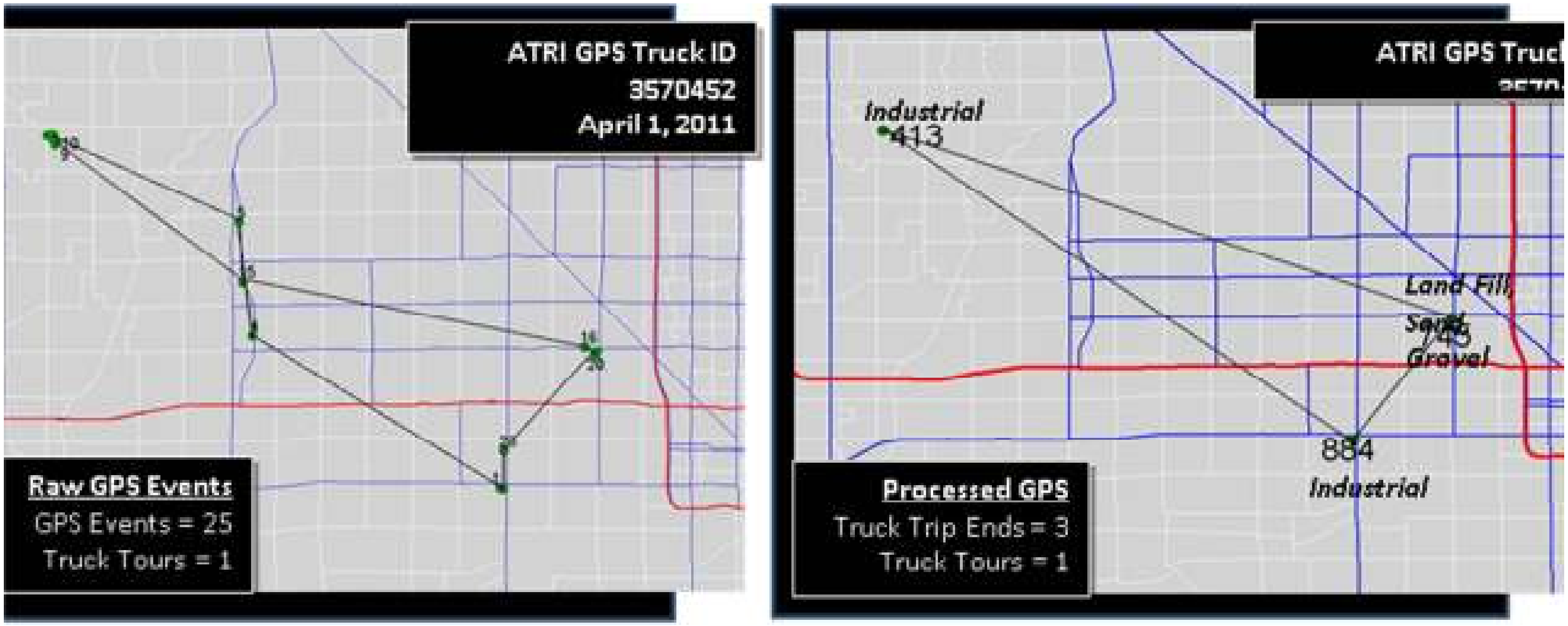
Based on all of the information that has been processed, it is possible to describe the tour for this example truck. From Table 5.1, the following information can be derived:

- The truck begins its tour at GPS event 3, which is in an industrial land use located in TAZ 884. This first trip in the tour begins at 3:47 a.m.
- The vehicle is moving in GPS event 4 and 5 and stopping in GPS event 6, which is in an industrial land use in TAZ 413. The travel time, based on the time between the starting GPS event and the stopping GPS event at 4:13 a.m., is 26 minutes.
- The truck remains at this location until GPS event 14 at 5:30 a.m., which means that the truck remained at this trip end for 87 minutes.
- It continues to move in GPS events 15 and 16 until it is stopping in GPS event 17, which is located in a Landfill Land Use in TAZ 745, at 6:01 a.m. This means that there was a 31-minute travel time between the two trip ends.
- The truck remains at this location until GPS event 22 at 7:34 a.m., which means that the truck remained at this trip end for 94 minutes.
- It continues to move in GPS event 23 until it is stopping in GPS event 24, which is located in an Industrial Land Use in TAZ 884, where the tour began, at 7:48 a.m. This means that there was a 15 minute travel time between the two trip ends. There is no duration at the stop calculated because it is the last stop of the tour.

Table 5.1 Attributes of ATRI GPS Truck Records for Truck ID 357402 on April 1, 2011

Primary Anonymized Data					Processed Data									
						Trip Distance (Miles)								
Truck_ID	Date	Time	Longitude	Latitude	Event	Last	Next	Time from Last (Minutes)	Time to Next (Minutes)	Speed from Last (MPH)	Speed to Next (MPH)	Event Type	TAZ	LU
357042	4/1/2011	3:27:06 AM	-112.1705	33.4353	1	0.00	0.00	–	3.93	0.00	0.00	stopped		
357042	4/1/2011	4:02:38 a.m.	-112.1704	33.4353	2	0.00	0.00	3.93	16.10	0.00	0.00	stopped		
357042	4/1/2011	3:47:08 a.m.	-112.1695	33.4353	3	0.06	6.39	16.1	12.87	0.21	29.79	First Starting	884	Industrial
357042	4/1/2011	4:00:00 a.m.	-112.2637	33.4838	4	6.39	2.53	12.87	2.63	29.79	57.6	moving		
357042	4/1/2011	4:02:38 a.m.	-112.2689	33.5200	5	2.53	4.56	2.63	11.1	57.6	24.67	moving		
357042	4/1/2011	4:13:44 a.m.	-112.3409	33.5475	6	4.56	0.00	11.1	0.27	24.67	0.42	Stopping		
357042	4/1/2011	4:14:00 a.m.	-112.3408	33.5475	7	0.00	0.06	0.27	2.1	0.42	1.78	stopped	413	Industrial
357042	4/1/2011	4:16:06 a.m.	-112.3398	33.5475	8	0.06	0.22	2.1	6.5	1.78	2.01	stopped	413	Industrial
357042	4/1/2011	4:22:36 a.m.	-112.3381	33.5447	9	0.22	0.03	6.5	0.63	2.01	2.64	stopped	413	Industrial
357042	4/1/2011	4:23:14 a.m.	-112.3377	33.5449	10	0.03	0.02	0.63	0.23	2.64	4.07	stopped	413	Industrial
357042	4/1/2011	4:23:28 a.m.	-112.338	33.5449	11	0.02	0.01	0.23	39.17	4.07	0.01	stopped	413	Industrial
357042	4/1/2011	5:02:38 a.m.	-112.3381	33.5449	12	0.01	0.05	39.17	20	0.01	0.15	stopped	413	Industrial
357042	4/1/2011	5:22:38 a.m.	-112.3383	33.5456	13	0.05	0.13	20	7.37	0.15	1.08	stopped	413	Industrial
357042	4/1/2011	5:30:00 a.m.	-112.3385	33.5475	14	0.13	5.22	7.37	15	1.08	20.88	Starting	413	Industrial
357042	4/1/2011	5:45:00 a.m.	-112.2673	33.5009	15	5.22	7.53	15	15	20.88	30.11	moving		
357042	4/1/2011	6:00:00 a.m.	-112.1391	33.4804	16	7.53	0.30	15	1.23	30.11	14.61	moving		
357042	4/1/2011	6:01:14 a.m.	-112.1345	33.4784	17	0.30	0.00	1.23	0.17	14.61	1.45	Stopping		
357042	4/1/2011	6:01:24 AM	-112.1346	33.4784	18	0.00	0.00	0.17	1.23	1.45	0.07	stopped	745	Landfill
357042	4/1/2011	6:02:38 AM	-112.1346	33.4784	19	0.00	0.03	1.23	80.6	0.07	0.02	stopped	745	Landfill
357042	4/1/2011	7:23:14 AM	-112.1351	33.4784	20	0.03	0.03	80.6	10.4	0.02	0.2	stopped	745	Landfill
357042	4/1/2011	7:33:38 AM	-112.1345	33.4785	21	0.03	0.04	10.4	0.87	0.2	2.91	stopped	745	Landfill
357042	4/1/2011	7:34:30 a.m.	-112.1344	33.4791	22	0.04	2.98	0.87	10.5	2.91	17.04	Starting	745	Landfill
357042	4/1/2011	7:45:00 AM	-112.1692	33.4472	23	2.98	0.83	10.5	3.9	17.04	12.77	Moving		
357042	4/1/2011	7:48:54 a.m.	-112.1702	33.4352	24	0.83	0.00	3.9	13.77	12.77	0.01	Stopping	884	Industrial
357042	4/1/2011	8:02:40 AM	-112.1702	33.4352	25	0.00	–	13.77	-	0.01	-	Last Stopped		

Figure 5.2 ATRI GPS Truck Records for Truck ID 357402 on April 1, 2011



This shows that GPS truck records can be processed to provide stop and tour information consistent with the information which would be provided by a truck trip diary. These calculations were automated and conducted for all of the GPS records. This allows the determination of possible trip and tours.

5.3 QA/QC of Processed Truck Trip Database

In order to further test the data processing for selecting trips from the GPS records, the following tests were done:

- **Visual Inspection of Stops.** The truck stops from a small sample of truck trips were overlaid onto a highway map. The start and end times of truck stops were also displayed for these sample truck trips. The sequence of stops in terms of time and position on the highway were examined to see if the truck trips have been created correctly and if they follow a certain path.
- **Aerial Imagery of Stops.** The truck stops from a small sample of truck trips will be overlaid on an aerial image of the region using Google Earth. The land uses of stops were displayed on to the shape file. The characteristics of the land uses (parking lot, warehouse, mall, etc.) were examined to see if the land uses defined for each stop appear reasonable.

In summary, after the examination of the processed truck trip database, it was determined that the criteria and thresholds used in this study were reasonable and corroborated by additional QA/QC measures. Further, random checks that were performed indicate the likelihood that the methodology employed successfully eliminates false positives, that is, stops that are not true trip ends.

6.0 Internal Truck Model Development

This chapter describes the various updates that were done to the internal truck model. It includes a literature review of light truck trip generation and distribution models that were estimated for other metropolitan regions, adopted approach to capture these in MAG's truck model, and data sources that were used to cross-check the reasonableness of light truck estimates. Also included in this chapter is the update of truck trip rates for medium and heavy trucks.

6.1 Light Commercial Truck Model

Before proceeding further it is useful to determine why an estimate of this vehicle class is desired, how it might be surveyed, how validation data might be obtained, and how those volumes might be utilized. A judgment must be made concerning what light trucks are. It is assumed that light trucks are as defined in air quality analyses for MOBILE and MOVE. Here classes of vehicles have been determined to emit grams of pollutants at different rates per mile depending on the vehicle's speed. The truck related MOBILE 6 vehicle classes are shown in Table 6.1.

Table 6.1 MOBILE 6 Truck Related Vehicle Classifications

Number	Abbreviation	Description
2	LDGT1	Light-Duty Gasoline Trucks 1 (0-6,000 lbs. GVWR, 0-3,750 lbs. LVW)
3	LDGT2	Light-Duty Gasoline Trucks 2 (0-6,000 lbs. GVWR, 3,751-5,750 lbs. LVW)
4	LDGT3	Light-Duty Gasoline Trucks 3 (6,001-8,500 lbs. GVWR, 0-5,750 lbs. ALVW)
5	LDGT4	Light-Duty Gasoline Trucks 4 (6,001-8,500 lbs. GVWR, > 5,751 lbs. ALVW)
6	HDGV2b	Class 2b Heavy-Duty Gasoline Vehicles (8,501-10,000 lbs. GVWR)
7	HDGV3	Class 3 Heavy-Duty Gasoline Vehicles (10,001-14,000 lbs. GVWR)
8	HDGV4	Class 4 Heavy-Duty Gasoline Vehicles (14,001-16,000 lbs. GVWR)
9	HDGV5	Class 5 Heavy-Duty Gasoline Vehicles (16,001-19,500 lbs. GVWR)
10	HDGV6	Class 6 Heavy-Duty Gasoline Vehicles (19,501-26,000 lbs. GVWR)
11	HDGV7	Class 7 Heavy-Duty Gasoline Vehicles (26,001-33,000 lbs. GVWR)
12	HDGV8a	Class 8a Heavy-Duty Gasoline Vehicles (33,001-60,000 lbs. GVWR)
13	HDGV8b	Class 8b Heavy-Duty Gasoline Vehicles (>60,000 lbs. GVWR)
14	LDDV	Light-Duty Diesel Vehicles (Passenger Cars)

Number	Abbreviation	Description
15	LDDT12	Light-Duty Diesel Trucks 1 and 2 (0-6,000 lbs. GVWR)
16	HDDV2b	Class 2b Heavy-Duty Diesel Vehicles (8,501-10,000 lbs. GVWR)
17	HDDV3	Class 3 Heavy-Duty Diesel Vehicles (10,001-14,000 lbs. GVWR)
18	HDDV4	Class 4 Heavy-Duty Diesel Vehicles (14,001-16,000 lbs. GVWR)
19	HDDV5	Class 5 Heavy-Duty Diesel Vehicles (16,001-19,500 lbs. GVWR)
20	HDDV6	Class 6 Heavy-Duty Diesel Vehicles (19,501-26,000 lbs. GVWR)
21	HDDV7	Class 7 Heavy-Duty Diesel Vehicles (26,001-33,000 lbs. GVWR)
22	HDDV8a	Class 8a Heavy-Duty Diesel Vehicles (33,001-60,000 lbs. GVWR)
23	HDDV8b	Class 8b Heavy-Duty Diesel Vehicles (>60,000 lbs. GVWR)
28	LDDT34	Light-Duty Diesel Trucks 3 and 4 (6,001-8,500 lbs. GVWR)

Source: User's Guide to MOBILE6.1 and MOBILE6.2, EPA420-R-03-010, August 2003, http://www.epa.gov/oms/models/MOBILE6/420r03010.pdf accessed on 7/20/2012.

While MOBILE (and MOVES) uses the terms light truck and heavy trucks, they do not use the term medium trucks. Medium truck is a term used by California EMFAC air quality analysis package, as shown in Table 6.2.

Table 6.2 EMFAC Vehicle Classes

Class	Description	Weight (GVW) Pounds
PC	Passenger Cars	All
T1	Light-Duty Trucks	0-3,750
T2	Light-Duty Trucks	3,751-5,750
T3	Medium-Duty Trucks	5,751-8,500
T4	Light-Heavy Duty Trucks	8,501-10,000
T5	Light-Heavy Duty Trucks	10,001-14,000
T6	Medium-Heavy Duty Trucks	14,001-33,000
T7	Heavy-Heavy Duty Trucks	33,001+
UB	Urban Bus	All
MC	Motorcycles	All
SB	School Bus	All
MH	Motor Homes	All

Source: EMFAC2007 version 2.30-User's Guide, California Air Resources Board, http://www.arb.ca.gov/msei/onroad/downloads/docs/user_guide_emfac2007.pdf accessed on 7/20/2012.

EPA attempted to develop a crosswalk between its vehicle classes and the vehicle classes used by U.S. DOT. Unfortunately, there was not a single vehicle classification system at U.S. DOT, and EPA attempted to match the vehicle classes used in the BTS's Vehicle Inventory and Usage Survey (VIUS) which was discontinued in 2002, and not the ongoing vehicle classification system used by FHWA in its vehicle reporting systems (VTRIS, HPMS, Traffic Monitoring Guide, etc.). This is shown in Table 6.1 by the usage of the terms Class2b through 8, which refer to VIUS classifications, as shown in Table 6.3.

The VIUS classes are still used by vehicle manufacturers to report sales information. Those classes are shown in Table 6.3, which also includes an example of actual trucks included in those classes. It also shows the VIUS identification of light, medium and heavy trucks. While they are not formally included in VIUS, classes 2a and 2b and classes 8a and 8b, as used by MOBILE, are also shown in that table.

Table 6.3 VIUS Truck Classes

Class	Weight Range	Examples
Light Duty		
Class 1	0 to 6,000 lbs.	Toyota Tacoma, Dodge Dakota and GMC Canyon.
Class 2	6,001 to 10,000 lbs.	Dodge Ram 1500 and the Ford F-150.
class 2a	6,001 to 8,500 lbs.	Commonly referred to as a light duty truck
class 2b	8,501 to 10,000 lbs.	Also called the light heavy-duty class.
Class 3	10,001 to 14,000 lbs.	Dodge Ram 3500, Ford F-350 and the GMC Sierra 3500.
Medium Duty		
Class 4	14,001 to 16,000 lbs.	Ford F-450 trucks, Dodge Ram 4500, and the GMC 4500.
Class 5	16,001 to 19,500 lbs.	GMC 5500. Dodge Ram 5500, and the Ford F-550
Class 6	19,501 to 26,000 lbs.	International Durastar, GMC Topkick C6500 and the Ford F-650
Heavy Duty		
Class 7	26,001 to 33,000 lbs.	GMC C7500 Vehicles in Class 7 and above require a Class B license to operate in the United States.
Class 8	Greater than 33,000 lbs.	These include all tractor trailer trucks.
class 8a	33,001 to 60, 000 lbs.	
class 8b	Greater than 60,000 lbs.	

Source: Cambridge Systematics from VIUS Users Guide and Wikipedia.

EPA commissioned a study[6] that developed a comparison of its air quality weight classes with the FHWA classes; including a determination of average weights by FHWA vehicle classes from FHWA weigh station data. That information is presented in Table 6.4, along with the body type and the VIUS classes associated with each FHWA Class.

Table 6.4 FHWA Vehicle Classifications with Average Weights

FHWA Class	Description	Average Vehicle Weight (lbs)	Body Type	VIUS Class
1	Motorcycles[a]	#N/A	Motorcycle	1
2	Passenger vehicles	4,500 – 9,000	Auto	1, 2
3	Two-axle, four-tire single-unit trucks	7,000 – 9,000	Pickup Truck	2, 3
4	Buses	25,000 – 29,000	Bus	6 & 7
5	Six-tire, two-axle single-unit vehicles	12,000 – 14,000	Single Unit	4 & 5
6	Three-axle single-unit vehicles	24,000 – 30,000	Single Unit	6 & 7
7	Four or more axle single-unit vehicles	41,000 – 58,000	Single Unit	8
8	Three or four axle single-trailer vehicles	26,000 – 31,000	COMBO1*	7
9	Five-axle single-trailer vehicles	48,000 – 58,000	COMBO1	8
10	Six-axle single-trailer vehicles	60,000 – 65,000	COMBO1	8
11	Five or less axle multi-trailer vehicles	50,000 – 61,000	COMBO2+[b]	8
12	Six-axle multi-trailer vehicles	56,000 – 63,000	COMBO2+	8
13	Seven or more axle multi-trailer vehicles	72,000 – 92,000	COMBO2+	8

[a] COMBO1 is a combination tractor, also known as a cab, with one trailer.

[b] COMBO2+ is a combination tractor with two or more trailers.

One common source of confusion in truck classifications is that both FHWA and VIUS use a numeric system and that while both the FHWA Scheme F Vehicle Classification system and the VIUS (as used by EPA's MOBILE) include a Class 3 and both refer to pickups, these do mean different things.

It is our opinion that after comparing all of these various truck classification systems that **light** trucks most commonly refer to FHWA Scheme F Class 3 pickup trucks; **medium** trucks refer to FHWA Scheme F Classes to 7 single unit trucks with 2 axles and 6 tires, or more than 2 axles; and **heavy** trucks refer to FHWA Scheme F Class 8-13 Combination tractor-trailer trucks. This is the usage

[6] ENVIRON International Corporation, Development Work for Improved Heavy-Duty Vehicle Modeling Capability Data Mining – FHWA Datasets, U.S. Environmental Protection Agency, July 2007.

that has been already adopted in MAG's truck model: Classes 5 to 7 as Medium trucks and Classes 8 to 13 as Heavy trucks.

From the above, it is suggested that there may not be an analytical reason to forecast the demand for commercial pickup trucks separate from all other, e.g., private usage, pickup trucks. The air emission impact will be the same regardless of the usage of the trucks. The pavement impact in terms of pavement load in Equivalent Single Axle Loads (ESALs) will be almost the same. Validation data and survey data provides information about pickup light trucks and autos. However, FHWA in its Traffic Monitoring Guide cautions that most automatic data collection techniques have difficulty in determining between autos (Class 2) and pickup trucks (Class 3). Further, the observed counts for FHWA Class 3 Scheme F include both personal use pickups and commercial pickups combined. While total registered vehicles can distinguish between commercial and personal registration, many commercially registered vehicles are also used for personal purposes.

Owing to all the aforementioned, many agencies choose not to estimate light commercial trucks (FHWA Class 3's) separately especially when it is very expensive to collect adequate survey data and their emissions are not that different from passenger cars (FHWA Class 2's). Also, there appears to be no source of validation data for light commercial trucks that is separate from personal use autos and light (i.e., pickup) trucks[7]. However, since MAG is interested in estimating light commercial trucks (FHWA Class 3's) exclusively, CS conducted a literature review on models that account for FHWA Class 3's. The findings from this review are presented in the ensuing section.

Literature Review

MAG's Truck Travel Model

MAG's current light truck model is reported here that will serve as a comparative measure when reviewing other MPO's light truck models. MAG's current light truck model was first developed in early 1990s by CS with the help of commercial vehicle travel surveys[8]. This was the first truck model at the MPO level in the U.S., shown in Table 6.5, which paved the way for many other urban truck models in the U.S.

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[7] Cambridge Systematics, Inc. *MAG Truck Study – FHWA Class 3 Vehicles.doc*, Technical Memorandum submitted to MAG, May 7, 2007.

[8] Cambridge Systematics, Inc. *Development of An Urban Truck Travel Model for the Phoenix Metropolitan Area*, Final Report, Prepare for Arizona Department of Transportation, February 1992.

Table 6.5 Current Light Truck Model Parameters

Variable	MAG Light Truck Model Trips per Unit
Total Households	0.15433
Retail employment	0.59091
Industrial employment	0.64087
Public employment	0.29491
Office employment	0.30925
Other employment	0.76348
Resident households	0.04004
Average Trip Length (from Current model)	9.8 miles

FHWA's Quick Response Freight Manual

FHWA's Quick Response Freight Manual[9] (QRFM) provides simple techniques and transferable parameters that can be used to develop commercial vehicle trip tables which can be merged with passenger vehicle trip tables. This manual is intended for organizations who want to update their truck models and be compliant with Federal regulations. The trip generation model reported in this manual is a variant of MAG's 1992 truck model where the trip rates were increased to account for under-reporting and the fact that the survey did not cover trips with one end outside the region. This is shown in Table 6.6 which has been borrowed heavily by various agencies to account for light trucks in various metropolitan regions.

Table 6.6 FHWA's QRFM Light Truck Model Parameters

Variable by Industry Sector	Four-Tire Commercial Vehicles (Trips per Day per Employee/Household)
Agriculture, Mining and Construction	1.11
Manufacturing, Transportation, Communications, Utilities, Wholesale trade	0.938
Retail trade	0.888
Office and services	0.437
Households	0.251

[9] Cambridge Systematics, Inc., *Quick Response Freight Manual*, Final Report submitted to FHWA, September 1996.

Los Angeles Metro Cube CARGO Model

CS developed the Phase II of LA Metro's Cube CARGO model which account for trucks in the six-county southern California region[10]. There are several models within Cube CARGO that capture different kinds of trucks depending upon their size, origin and destination, commodities carried, and freight versus non-freight vehicles. The "service model" of Cube CARGO estimates truck traffic that is not represented by the commodity flow and other freight carrying truck models. This model estimates truck traffic pertaining to Class 3 category that have not been included anywhere else in the CARGO model.

There is very little available data on these trips that could be used to update or calibrate the "service model." There was data collected as part of a previous FHWA research project on accounting for commercial vehicles in travel models that identified the magnitude and distribution of service vehicles. This in conjunction with the California DMV data was used to define the service model parameters in CARGO, as shown in Table 6.7.

Table 6.7 LA Metro's Service Model

Variable	Trip Rate per Day
Population	0.1229
Industrial Employees	0.1
Construction Employees	0.1
Agriculture Employees	0.1

Puget Sound Regional Council (PSRC) Truck Travel Model

PSRC truck model captures light, medium and heavy trucks where light trucks are defined as four or more tires, two axles, and less than 16,000 lbs gross vehicle weight. These light trucks also include non-personal use of cars and vans, that is, all commercial Class 3s are included. As the truck counts do not separate light truck from passenger cars, light trucks were primarily included in the PSRC truck model so that all vehicles are represented in the traffic assignments. The production and attraction rates for light trucks as shown in Table 6.8 were actually derived from the QRFM but adjusted or calibrated to observed (autos) data during model validation[11].

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[10] Cambridge Systematics, Inc., *Calibrate and Validate Phase I Cube CARGO and Cube Dynasim Model*, Prepared for LA Metro, March 2008.

[11] Cambridge Systematics, Inc., *PSRC Travel Model Documentation (Updated for Congestion Relief Analysis)*, Final Report Prepared for Washington DOT and PSRC, September 2007.

Table 6.8 PSRC Light Truck Production and Attraction Rates

Variable by Sector	PSRC Light Truck Production Rates (per Employee/ Household per Day)	PSRC Light Truck Attraction Rates (per Employee/ Household per Day)
Agriculture/Forestry/Fishing	0.3486	1.2311
Mining	0.3486	44.8093
Construction	0.3486	0.2418
Manufacturing – Products	0.2946	0.2414
Manufacturing – Equipment	0.2946	0.2414
TCU	0.2946	0.4754
Wholesale	0.2946	0.1369
Retail Trade	0.2789	0.0469
FIRES	0.1372	0.1488
Education and Government	0.1372	0.0903
Households	0.0789	0.1620

Baltimore Regional Council (BMC) Commercial Vehicle Model

BMC's regional travel forecasting model includes three types of trucks[12]. These truck trips are defined based on FHWA's "F-13" classification scheme. "Heavy" trucks are defined as vehicles with three or more axles (F6 – F13 in the FHWA scheme); "Medium" trucks are vehicles with two axles and six tires (FHWA's F5); and "Commercial" trucks refer to those trucks that are mainly business-oriented and are not used for personal transportation, but do not involve a Medium or Heavy Truck. The Commercial category includes a wide range of light trucks: pickups, vans, minivans, and sport-utility vehicles (SUVs), as well as passenger cars that are used for business purposes. Light trucks, vans, and SUVs used for personal transportation are not included here.

This is a new category of trip that has not been recognized before in BMC's regional travel demand model. It includes package delivery vehicles, postal vehicles, couriers, equipment repair and service technicians, craftsmen (carpenters, plumbers, etc.), government workers, taxis, and many other types of light-duty vehicles.

[12] Allen, W. G, *Development of Commercial Vehicle Travel Model*, Final Report Prepared for Baltimore Regional Council, June 2002.

The basic methodology of this study relies on developing a Commercial trip table from counts. For this project, BMC staff conducted new counts of Commercial traffic at 113 locations. The consultant and staff agreed that the best way to define "Commercial" for the purposes of these counts was that a Commercial vehicle is any vehicle that displays any text, logo, or trademark, or that is transporting equipment of an obviously commercial nature. The premise of this analysis was that it should be possible to use this data to develop a model of the percent Commercial traffic. For each observation, the dependent variable is the percent Commercial traffic and a set of independent variables namely functional class group (freeway, arterial, collector), area type (CBD, urban, suburban, rural), number of lanes, and percent of other vehicle types in the count stream.

The following logit-based Commercial count model was developed:

Percent "Commercial" = 1/(1 + e^{U}***)***

U = cJur + cFD + 0.0042*CAPCLASS – 0.0058*SPDCLASS – 0.0111*LANES – 0.0472*pBus + 0.0004*F1 – 0.00015*F7 + 0.0005*F11 – 0.0005*F12

Where,

CAPCLASS = network capacity class

SPDCLASS = network speed class

LANES = number of lanes (each way)

pBus = percent of traffic count that is buses

F1 = classification count (motorcycle), both directions

F7 = classification count (4 axle, single unit truck), both directions

F11 = classification count (5 axle, multiple unit truck), both directions

F12 = classification count (6 axle, multiple unit truck), both directions

cJur = bias coefficient by jurisdiction

cFD = bias coefficient by facility group and density code.

After computing the percent of Commercial vehicular traffic on a link level basis, the next step was to develop an interim trip table so that a more precise Commercial trip table can be developed at the TAZ level. For this, the following model was developed to estimate Commercial trips at the TAZ level.

Commercial Trips = 0.454 * INDEMP + 0.501 * RETEMP + 0.454 * OFFEMP + 0.146 * HH

Where,

INDEMP is Industrial Employment

RETEMP is Retail Employment

OFFEMP is Office Employment

HH is Households

The trip distribution of Commercial trucks, the following gamma function was adopted:

$$\mathbf{F = \alpha * t^{\beta} * e^{(\gamma t)}}$$

Where,

t = travel time, minutes

α, β, γ = calibrated coefficients

The estimated trip length for Commercial trucks was 16.2 minutes, which is about seven percent lower than the Medium Truck value of 17.4 minutes.

FHWA Study on "Accounting for Commercial Vehicles in Urban Transportation Models"

For FHWA, CS conducted extensive research to evaluate the magnitude and distribution of commercial vehicles in urban transportation planning models. This research effort included the following three major tasks:

- The first was to assess recent and current literature for different types of commercial vehicles relevant to the treatment of commercial vehicles in urban transportation models. As part of this work, a set of commercial vehicle categories was established[13].
- The second was to compile available data and information and estimate the magnitude and spatial/temporal distribution of different types of commercial vehicles. As part of this work, the commercial vehicle categories were refined and prioritized[14].
- The third was to evaluate methods and data sources that can be used to forecast commercial vehicles in urban transportation planning models[15].

[13] Cambridge Systematics, *Accounting for Commercial Vehicles in Urban Transportation Models, Task 2: Literature Review,* Final Report Prepared for FHWA, January 2003.

[14] Cambridge Systematics, *Accounting for Commercial Vehicles in Urban Transportation Models, Task 3: Magnitude and Distribution,* Final Report Prepared for FHWA, November 2003.

[15] Cambridge Systematics, *Accounting for Commercial Vehicles in Urban Transportation Models, Task 4: Methods, Parameters and Data Sources,* Final Report Prepared for FHWA, February 2004.

The trips made by commercial vehicles were organized into three groups based on what is being carried and what economic, demographic and land use factors influence their magnitude and distribution. The three groups are:

- Commercial vehicles moving people,
- Commercial vehicles moving goods, and
- Commercial vehicles providing services.

These three groups are further subdivided into 12 specific categories of commercial vehicles as shown in Table 6.9.

Table 6.9 Commercial Vehicles by Type and Purpose

Commercial Vehicle Type		Purpose
1.	School Bus	Movement of People
2.	Fixed Shuttle Services at Airports, Stations, etc.	Movement of People
3.	Private Transportation: Taxi, Limos, Shuttles	Movement of People
4.	Paratransit: Social Services, Church Buses	Movement of People
5.	Rental Cars	Movement of People
6.	Package, Product, and Mail Delivery (USPS, UPS, FedEx)	Movement of Goods
7.	Urban Freight Distribution, Warehouse Deliveries	Movement of Goods
8.	Construction Transport	Movement of Goods
9.	Safety Vehicles: Police, Fire, Building Inspections, Tow Trucks	Movement of Goods
10.	Utility Vehicles: Trash, Meter Readers, Maintenance, Plumbers, Electricians	Services
11.	Public Service: Federal, State, City, Local Government	Services
12.	Business and Personal Services: Personal transportation, Realtors, Door-to-Door Sales	Services

For each of these 12 categories of commercial vehicles, CS developed three categories of methods to forecast commercial vehicles for urban transportation planning models. These are:

- The Aggregate Demand Method, which estimates fleet size, trips, and VMT by commercial vehicle category directly from regional estimates of demographic data (such as population and employment) using national default parameters;
- The Network-based Quick Response Method, which estimates trips, origin and destinations and routes for each type of commercial vehicle using zonal estimates of demographic data and roadway networks using national default parameters; and

- The Model Estimation Method, which estimates trips, origin and destinations and routes for each type of commercial vehicle using zonal estimates of demographic data and roadway networks using parameters derived from local survey data.

The effort to quantify the magnitude and distribution of commercial vehicle travel relied on a series of data sources that provided data on vehicles, trips, trip lengths and/or vehicle miles traveled in each of 12 commercial vehicle categories. Based on these data, commercial vehicle travel was estimated for 13 urban areas in the U.S. Most of the data sources provided data for multiple categories of commercial vehicles (such as the registration data and the commercial vehicle surveys) but some data sources were category-specific (such as the school bus fleet data). The primary data sources that were used to develop commercial vehicle parameters are provided below:

- Commercial vehicle survey data was available in Detroit, Atlanta, Denver and the Piedmont-Triad area (Winston-Salem, Greensboro, and High Point).
- California Department of Motor Vehicle data was available for Los Angeles, San Francisco, San Diego and Sacramento.
- The National Transit Database for paratransit vehicles was available for 198 cities in the U.S., including all 13 urban areas in the study area (Los Angeles, San Francisco, Detroit, Atlanta, San Diego, Houston, Denver, Portland, Sacramento, Orlando, Winston-Salem, Greensboro, and High Point).
- United States Postal Service data was obtained for seven urban areas (Atlanta, Denver, Detroit, Houston, Greensboro, Orlando, and Portland).
- School bus fleet surveys were available for the largest 100 school districts, including 10 of the urban areas in the study area (Los Angeles, Detroit, Atlanta, San Diego, Houston, Denver, Portland, Winston-Salem, and Greensboro).
- The Taxi Fact Book was available for all major cities in the U.S., including all 13 urban areas in the study area (Los Angeles, San Francisco, Detroit, Atlanta, San Diego, Houston, Denver, Portland, Sacramento, Orlando, Winston-Salem, Greensboro, and High Point).
- The Airport Ground Access Planning Guide was available for 27 cities in the U.S., including five cities in our study (Los Angeles, San Francisco, Houston, Portland and Orlando).

There were many other data sources reviewed and used to support the estimation of the magnitude and distribution of commercial vehicles in this research effort. One significant contributor was the Vehicle Inventory and Use Survey (VIUS), which was used to estimate average miles traveled per day for the 12 vehicle categories, but these data were not specific to an urban area but to all urban areas in a state.

Methodology

Based on the literature review of various light commercial truck models and data sources, CS used the FHWA research project as a guidebook to develop MAG's light truck generation and distribution models. Also, for the MAG truck model, commercial vehicles pertaining to the 'movement of people' were not necessary to be accounted for as these are captured in other parts of the MAG travel model (such as special generator model, visitor model, and non-home based trips in the passenger model). Therefore, this methodology is only to account for the seven types of commercial vehicles pertaining to 'moving goods' and 'providing services'. That is, categories 6 to 12 in Table 6.9 are only considered in this analyses, as shown below.

- Package, Product, and Mail Delivery (USPS, UPS, FedEx)
- Urban Freight Distribution, Warehouse Deliveries
- Construction Transport
- Safety Trucks: Police, Fire, Building Inspections, Tow Trucks
- Utility Vehicles: Trash, Meter Readers, Maintenance, Plumbers, Electricians
- Public Service Trucks: Federal, State, City, Local Government
- Business and Personal Services Trucks: Personal transportation, Realtors, Door-to-Door Sales

Two alternate methods are presented here that are derived directly from the FHWA Accounting for Commercial Vehicles in Urban Transportation Models Task 4 report on Methods, Parameters, and Data Sources. These two methods are used to compute the daily VMT estimates by specific commercial vehicle category, and the data for these two methods was compiled from various models across the country.

VMT Method 1

The first method was derived by researching into fleet size rate by land use, employment, and other data that was available, along with the miles traveled per vehicle per day for each category of commercial vehicle. These rates and miles traveled are then used to an estimate of daily VMT. The primary advantage of this approach is that it extends the typical commercial vehicle forecasting procedures used by MPOs to a broader range of commercial vehicle and trip types. This technique is primarily applicable at a regional (macro) level of detail.

$$\boldsymbol{FleetSize_c = VehicleRate_c * SocioeconomicData}$$

Where:

$FleetSize_c$ = Number of commercial vehicles of category 'c'

$VehicleRate_c$ = Number of commercial vehicles of category 'c' per unit variable(s)

SocioeconomicData = Data such as population/employment/tourists, set by category 'c'

The number of commercial vehicles or Light Trucks is estimated using the above equation.

The miles traveled per vehicle per day for commercial vehicle categories are available from a variety of sources, identified in the FHWA Task 3 report. Hence, it is possible to estimate the VMT for commercial vehicle categories, as follows:

$$\boldsymbol{DailyVMT_c = VMTperVehicle_c \times FleetSize_c}$$

Where,

$DailyVMT_c$ = Total Daily Vehicle Miles Traveled for commercial vehicles in category 'c'

$FleetSize_c$ = Number of commercial vehicles of category 'c'

$VMTperVehicle_c$ = Average vehicle miles traveled per vehicle for commercial vehicles of category 'c'. This is calculated as the average number of trips per day * the average trip length in miles.

These computations for the seven types of commercial vehicles that are Light Trucks is shown in Table 6.10. Also shown in this table are the trip rates derived from the ratio of total light truck trips and the values of the variables used for each light truck category.

VMT Method 2

The second method was derived by researching into several MPO models that account for VMT of Light Trucks with the help of commercial vehicle surveys and establishment surveys. This uses a percent of total vehicular VMT for each commercial vehicle category. This method is used only to cross-check or provide reasonableness of the VMT produced by Method 1. These estimates are also provided in Table 6.11.

Table 6.10 Light Truck VMT Estimates by FHWA Method 1

Commercial Vehicle Type	Fleet Size				Trip Length (Miles)[a]	Total Vehicle Trips		VMT1	Light Truck Trip Rate
	Fleet Rate[a]	Variable	Value of Variable	Fleet Size		Trips per Truck[a]	Total Light Truck Trips		
Package, Product, and Mail Delivery (USPS, UPS, FedEx)	0.005	Total Employment	1,765,752	8,829	19.0	4.0	35,315	670,986	0.02
Urban Freight Distribution, Warehouse Deliveries	0.02	Population	4,534,274	90,685	12.7	5.1	462,496	5,873,699	0.102
Construction Transport	0.009	Total Employment	1,765,752	15,892	12.6	4.1	65,156	820,969	0.0369
Safety Vehicles: Police, Fire, Building Inspections, Tow Trucks	0.0006	Population	4,534,274	2,721	9.0	5.4	14,691	132,219	0.00324
Utility Vehicles: Trash, Meter Readers, Maintenance, Plumbers, Electricians	0.001	Population	4,534,274	4,534	6.4	3.5	15,870	101,568	0.0035
Public Service: Federal, State, City, Local Government	0.005	Population	4,534,274	22,671	8.9	3.3[b]	73,682	657,470	0.01625
Business and Personal Services: Personal transportation, Realtors, Door-to-Door Sales	0.02	Population	4,534,274	90,685	15.0	3.0	272,056	4,080,847	0.06
Total Light Trucks (Base Year 2011)				**236,018**	**11.9**	**4.1**	**939,267**	**12,337,757**	

[a] Source: Tables 2.12, 2.14, 2.18, 2.21, 2.23, 2.25, 2.27 of FHWA Commercial Vehicles Task 4 Report, February 2004.

[b] Average of Utility Vehicles (3.5) and Business/Personal Services (3.0).

Table 6.11 Light Truck VMT Estimates by FHWA Method 2

Commercial Vehicle Type	Rate[a]	Variable	Value of Variable	VMT2
Package, Product, and Mail Delivery (USPS, UPS, FedEx)	0.20	Total Employment	1,765,752	353,150
Urban Freight Distribution, Warehouse Deliveries	4.40%	Total VMT	91,817,704	4,039,979
Construction Transport	0.60%	Total VMT	91,817,704	550,906
Safety Vehicles: Police, Fire, Building Inspections, Tow Trucks	0.40%	Total VMT	91,817,704	367,271
Utility Vehicles: Trash, Meter Readers, Maintenance, Plumbers, Electricians	0.30%	Total VMT	91,817,704	275,453
Public Service: Federal, State, City, Local Government	1.600%	Total VMT	91,817,704	1,469,083
Business and Personal Services: Personal transportation, Realtors, Door-to-Door Sales	3.60%	Total VMT	91,817,704	3,305,437
Total Light Trucks (Base Year 2011)				**10,361,280**

[a]Source: Tables 2.12, 2.14, 2.18, 2.21, 2.23, 2.25, 2.27 of FHWA Commercial Vehicles Task 4 Report, February 2004.

Highlights of Light Truck VMT Analyses

Here are some key findings from our analyses of light truck commercial VMT (FHWA Class 3) estimates from different methods and sources:

- The FHWA Method 1 produces commercial Light Truck VMT of **12.33 million (13 percent of total VMT)**.
- The FHWA Method 2 produces commercial Light Truck VMT of **10.36 million (11 percent of total VMT)**.
- MAG's current base year 2010 light truck model produces Light Truck VMT of **16.79 million (18 percent of total VMT)**:
  - The application of MAG's current base year 2010 light truck trip rates produces about 1.19 million Light Truck Trip Ends (after generation), which is about 44 percent lower than the Light Truck OD Trip Table total of 1.71 million; and
  - This could be due to calibration of the Light Truck Model, but it is not conclusive at this point.
- The 1.19 million Light Truck Trip End estimate (after generation), when multiplied by an average trip length of 9.8 miles (after distribution), yields a Light Truck VMT of **11.67 million (13 percent of total VMT)**.

Steps to Update Light Truck (FHWA Class 3 Commercial Vehicles) Model

As presented above, the FHWA Method 1 and the current base year 2010 light truck model (without any adjustments) produces about the same amount of Light Truck VMT (13 percent of total VMT). Therefore, the following steps were undertaken to updating the Light Truck Model for the new base year of 2011:

1. The FHWA VMT Method 1 was used to estimate Light Truck Trip Ends (in generation) at the TAZ level. The trip rates are presented in Table 6.10.
2. The existing light truck gravity model for trip distribution was implemented and calibrated to produce an average trip length of 9.8 miles.
3. As the percent of Light Trucks varies from region to region and by commercial purpose (moving goods vs. providing services), the estimate of fleet sizes was adjusted for each category during Light Truck Model Calibration.
4. In addition to trip generation and distribution parameters, the FHWA project also looked into the time of day distribution of Light Trucks (Class 3's) across many metropolitan regions. These are presented in Table 6.12 below by commercial purpose category, and the average time of day distribution was used to allocate Light Trucks into appropriate MAG model time periods.
5. As mentioned earlier in the "Background" section of this chapter, there is no known source of Light Truck Count database that includes only Class 3 commercial vehicles; therefore, the Light Trucks were combined with Passenger Cars during validation.

Table 6.12 Time of Day Distribution of Light Trucks

MAG Model Time Periods	Package, Product, Delivery	Urban Freight	Construction	Safety	Utility	Public Service	Business/ Personal Service	Average
AM 6am – 9am	11%	7%	8%	31.5%	27.5%	25%	11%	17%
MD 9am – 2pm	60%	60%	61%	26%	41%	42%	53%	49%
PM 2pm – 6pm	29%	23%	21%	31.5%	27.5%	33%	22%	27%
NT 6am – 6pm	0%	10%	10%	11%	4%	0%	14%	7%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Advantages of the Adopted Methodology

The adopted methodology has the following advantages over the existing Light Truck Model methodology:

- The source of the current Light Truck Trip Rates (see Table 6.5) is the 1992 survey which is now too old and so needs to be updated. Also, the expansion factors for Light trucks used in the 1992 survey are very large, which was due to a lower sample and fewer strata (two things that are critical to collecting a robust sample).

- The FHWA Method 1 uses a variety of data sources and is a function of population and employment as it should be. Commercial vehicle survey data from 13 metropolitan regions where used along with DMV data and U.S. Census Bureau's Vehicle Inventory Use Survey (VIUS).
- The FHWA Method 1 can estimate up to seven types of Light Trucks, and offers flexibility in terms of calibrating each type of Light Truck individually if data is available to do so.

Reasonableness Checks

The following reasonableness checks against other data sources were performed:

- **AZDOT DMV Registration Database.** The DMV database for 2011 was used to estimate the total number of Light Trucks which were further stratified into 'personal' and 'commercial' based on the license plates. MAG derived this information from AZDOT, and the estimate of the number of Light Trucks used for commercial purposes registered in the counties that forms the MAG modeling region is 215,000. Though all registered Light Trucks do not necessarily operate and generate VMT in the MAG region, this estimate was considered to be reliable and the Light Truck trip generation model will be calibrated correspondingly.
- **County Vehicle Fleet Mix**. MAG's air quality division produces a set of MOBILE6 inputs using county vehicle fleet mix by county, which was also used to cross-check the fleet size distributions produced by the recommended FHWA Method 1.
- **Current MAG Truck Model**. The current truck model, though it produces a high estimate of Light Truck VMT, was also used to cross check the reasonableness of the distribution of light trucks in the MAG region.

A review was undertaken of the model outputs from the current 2010 MAG model runs for the expanded TAZ system. The socioeconomic data, daily link miles traveled (DVMT) by vehicle type/trip table, and daily OD trips by vehicle type were provided by MAG staff. These statistics were used to derive average trip lengths (DVMT/trip) and daily trip rates as shown in Table 6.13.

Table 6.13 MAG 2010 Model Statistics

SED 2010	
Total Population	4,534,274
Total Employment	1,765,752
2011 Link DVMT	

Autos		62,794,179
Light Trucks		16,792,579
Medium Trucks		5,433,412
Heavy Trucks		6,797,534
2011 OD Daily Trips		
Autos		21,691,900
Light Trucks		1,714,142
Medium Trucks		313,535
Heavy Trucks		306,019
DVMT per Daily Trip by Vehicle Type (Miles)		
Autos		2.89
Light Trucks		9.80
Medium Trucks		17.33
Heavy Trucks		22.21
Daily Trip Rates by Vehicle Type	**Per Person**	**Per Employee**
Autos	4.78	12.28
Light Trucks	0.38	0.97
Medium Trucks	0.07	0.18
Heavy Trucks	0.07	0.17

It was determined from national sales figures[16] that pickup trucks represent 13 percent of the total sales of all vehicles in 2010. If this percentage of sales is also true for MAG, then the pickup truck trip rates for private use should represent 15 percent (= 13%/(100%-13%)) of what are being shown as trip rates for "auto" in the auto passenger model. In the MAG auto passenger model, "autos" are actually all vehicles used for personal purposes, including passenger cars and private use pickup trucks.

The daily light truck trip rates shown at the bottom of Table 6.13 are not 15 percent, but are instead 8 percent (=0.38/4.78 of rates per population; =0.97/12.28 of the rates per employee) of the "auto" rates. This confirms that the current MAG model light truck trips are indeed commercial pickup trucks and not all pickup trucks. This also suggests that number of registered commercial pickups traveling on an average weekday day, as represented by the model day,

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[16] http://news.pickuptrucks.com/2011/01/the-ultimate-guide-to-us-pickup-truck-sales-in-2010.html, accessed on July 26, 2012.

might be only slightly higher (=8%/(15%-8%) than the private, (e.g., personal, passenger) pickups traveling on that same average weekday.

Since the number of light trucks might be same as personal pickup trucks, it might seem appropriate to scale their behavior and trip tables from the "auto" trip table. However, as shown in Table 6.13, the average trip length for "auto' is 2.89 miles while the average trip length for light trucks is 9.8 miles. Scaling the "auto" trip tables would not be appropriate because it would retain the same average trip length. Scaling from the medium light internal trip table would also be problematic because the average trip length for medium truck is 17.33 miles, and its average distance is less than twice (17.33/9.80) that of light commercial trucks while light trucks are less than one third (=2.89/9.80) of the average distance for autos.

Trip Distribution

The light truck trips are distributed using the in-built gravity model in TransCAD. The travel time skim matrix is used as the impedance in the trip distribution model. The friction factor table was developed using the following equation:

$$\textit{Friction factor} = e^{(-coeff\,*\,time)}$$

Where,

coeff = 1 / (average trip length in minutes)

Average trip length in minutes = (Target trip length in miles*60)/average speed.

The average speed is calculated for each of the OD pairs within the model using the travel time and distance skims as shown below.

$$\textit{Average speed} = \frac{\sum_{z}\frac{length*60}{time}}{z}\ mph$$

Where,

Z = Number of OD pairs.

The gravity model was run using the initial friction factor table and the production-attraction table to develop a preliminary trip table. During calibration process, the target trip length of 9.8 miles was used to adjust the constant in the friction factor equation.

6.2 Medium Truck Model

Trip Generation

There was no new data collected or acquired for updating the medium truck trip model parameters such as trip rates, trip lengths and land use to land use trip interchange percentages for the gravity model. Therefore, the data an NCFRP project was used, which looked into Trimble truck GPS data for single unit medium trucks (FHWA Classes 5 to 7)[17]. In this project, Trimble GPS data was purchased and processed for four metropolitan regions including Los Angeles, Phoenix, Baltimore and Chicago. Some of the key statistics that were computed include number of origins per truck per day, land use interchange percentages and time of day factors.

Table 6.14 shows a summary of medium trucks by industry sector and the number of origins or stops per truck per day for the Phoenix region. Also shown this table is a cross-walk between the NCFRP land use categories and the MAG model categories, which was used to adjust the existing medium truck trip rates and land use interchanges. Before using the data presented in Table 6.14, the number of trucks were expanded to the MAG regional truck populations by land use category.

Table 6.14 Number of Truck Stops per Medium Truck by Land Use from NCFRP Report 8

Land Use in NCFRP Study	Number of Trucks	Number of Origins per Truck per Day	Land Use in MAG Model
Industrial	2,446	0.9	Manufacturing
Low density	2,554	4.33	Office, Service, Transportation/Warehousing and government
Other high density employment	2,163	0.97	Retail
Residential	2,258	2.72	Households
Retail and commercial	2,693	3.49	Other, Farming and Construction

Table 6.15 shows the medium truck populations that were derived during the previous truck model update (2007) based on 2002 Vehicle Inventory Use Survey (VIUS) data and 2007 DMV registration data by vehicle body type. This is documented in more detail in the previous truck model update report[18].

[17] Cambridge Systematics, Inc., Freight-Demand Modeling to Support Public-Sector Decision-making, NCFRP Report 8, 2010.

[18] Cambridge Systematics, *MAG Internal Truck Travel Survey and Truck Model Development Study*, December 2007.

Table 6.15 Medium Truck Populations in the MAG Region

Business Sector	Medium Trucks
Agriculture	1,602
Construction	15,363
Manufacturing	4,325
Mining	673
Retail trade	4,599
Services	10,320
Transportation and warehousing	79,632
Utilities	7,041
Wholesale trade	5,711
Total	**129,266**

After expanding the NCFRP data to the MAG region, the number of expanded truck trips by land use are computed, which serves as the control or target number of trucks trips necessary for the new medium truck model. Therefore, the ratio of these expanded totals and existing medium truck trips from the model is the adjustment factor. These factors are computed by land use and are applied to the existing medium truck trip rates to come up with new updated trip rates.

Table 6.16 shows the new trip rates by land use. Most of these rates are identical for both productions and attractions, except for retail and construction as indicated in the table. Table 6.17 shows the total number of medium truck trip ends computed by the updated truck trip rates.

Table 6.16 Medium Truck Trip Rates

Land Use	Total Employment	Retail Employment	Retail Squared	Total Population	LN (Households)	Wholesale Employment	Mining Employment	Farming Employment	Manufacturing Employment
Retail	–	0.0481	0.00005	–	–	–	–	–	–
Constr.	0.0166	–	–	0.0089	–	–	–	–	–
Farming	–	–	–	–	–	–	–	0.4534	–
Households	–	–	–	–	1.5287	–	–	–	–
Govt.	0.0019	–	–	–	–	–	–	–	–
Warehouse	–	–	–	–	–	0.9813	–	–	–
Transp.	–	–	–	–	–	0.0236	–	–	–
Office	0.0019	–	–	–	–	–	–	–	–
Other	0.0019	–	–	–	–	–	–	–	–
Manufac.	–	–	–	–	–	–	–	–	0.0250

Table 6.17 Medium Truck Trip Ends

Land Use	Trip Ends
Retail	16,051
Construction	69,267
Farming	4,191
Households	19,152
Government	3,337
Warehousing	75,431
Transportation	1,812
Office	3,337
Other	3,337
Manufacturing	3,893
Total	**199,806**

Trip Distribution

Friction Factors

The medium trucks are distributed using a gravity model that uses that is a function of congested travel times and the degree of difficulty of travel between any two zones. The degree of difficulty, also known as the friction factor, is computed as a negative exponential function of the average trip time from origin TAZ to destination TAZ.

$Friction\ Factor_{ij} = e^{(coeff * t_{ij})}$

Where,

Coeff = Parameter derived from observed data (-0.032);

t_{ij} = Travel time for any given 'ij' pair of zones.

The parameter in the exponential function is typically calculated from observed trip length frequency distributions, which is further adjusted to provide the best fit with the observed average trip length. As there was no survey conducted for medium trucks nor was there any GPS data, the previous model's coefficient was retained in this gravity model. It was adjusted until the derived friction factors enabled the model to match the observed average trip length, also obtained from the previous 2007 medium truck trip diary surveys.

Land Use to Land Use Interchanges

In typical trip distribution models, aggregating truck trip ends by purpose and then distributing those aggregated productions and attractions would link types of land use categories for which no activity was identified in the survey, and for which none is expected. Therefore, an innovative process was developed in the previous internal truck model update, which is used in this update as well. It is based on the recognition that trip distribution is a connection between a land use category serving as a production and a land use category serving as an attraction. For example, in passenger modeling, Home-Based Work (HBW) passenger trips are those that occur between the Home land use production and the Work land use attraction. The HBW productions are the percentage of total home productions that will be distributed to work attractions, and the HBW attractions are the percentage of total work attractions that will be distributed to home productions. Using the same principle, separate gravity models for different land use interchanges were developed because the movement of truck trips from one land use to another are very distinct when compared against different land use exchanges. As there are 10 different land uses for which trip rates are derived, the number of land use exchanges that are possible are 10 times 10 or 100 gravity models. This approach effectively retained the land use information throughout the trip distribution step.

The concept of retaining the land use distinctions for truck trips is at the heart of this innovative internal truck distribution concept[19]. Prior to each of the 100 trip distributions, it would be necessary to determine what percentage of the total trips at the production land use are to each of the attraction land uses; and what percentage of the total trips at the attraction land use are from each of the production land uses. As applied to the productions for each zone for the production land use and the attractions for each zone for the attraction land use, this defines the P_i times A_j portion of the standard gravity model equation, where friction factors between zones is the other term. In this innovative gravity model, in addition to the standard terms, the land use to land use percentages are also inputs as shown in the equation below.

$$T_{ilu_m lu_n} = PctP_{lu_m lu_n} * P_{ilu_n} * \frac{PctA_{lu_n lu_m} * A_{jlu_n} * FF_{ij}}{\sum_j PctA_{lu_n lu_m} * A_{jlu_n} * FF_{ij}}$$

Where,

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[19] Kuppam, A., D. Beagan, R. Copperman, R. Thammiraju, V. Livshits, L. Vallabhaneni, S. Nippani, *A Hybrid Approach to Develop Freight Model from Commercial Vehicle Travel Surveys and Commodity Flow Data*, Presented at the Innovations in Travel Modeling Conference, Tempe, AZ, May 9-12, 2010.

$T_{ilu_m lu_n}$ = Truck trips in a zone 'i' for land use 'm' to land use 'n';

$PctP_{lu_m lu_n}$ = Percentage of trips between land use 'm' to land use 'n';

P_{ilu_n} = Productions in zone 'i' of land use 'n';

$PctA_{lu_n lu_m}$ = Percentage of trips between land use 'n' to land use 'm';

A_{jlu_n} = Attractions in zone 'j' of land use 'n';

FF_{ij} = Friction factor for 'ij' pair.

The land use to land use trip interchanges for medium trucks were derived from the NCFRP project as shown in Table 6.18. This table shows the production and attraction percentages by land use category, which is used to create a similar matrix for the MAG land use categories for medium trucks.

Using the cross-walk between NCFRP land uses and the MAG model land uses, as shown in Table 6.14, the trip interchange percentages among MAG land sues were determined. These are presented separately for productions and attractions in Tables 6.19 and 6.20.

Table 6.18 Medium Truck Trip Interchange Percentages from NCFRP Report 8

	Industrial	Other High-Density Employment	Retail and Commercial	Residential	Low Density
Industrial	52.2%	5.3%	22.0%	9.4%	11.1%
	52.6%	6.6%	10.8%	3.5%	6.6%
Other High-Density Employment	6.7%	42.5%	21.5%	17.6%	11.6%
	5.2%	41.5%	5.1%	5.1%	5.4%
Retail and Commercial	10.1%	8.2%	48.8%	21.4%	11.5%
	21.1%	21.4%	49.6%	16.5%	14.2%
Residential	6.9%	5.5%	15.6%	65.5%	10.0%
	6.6%	18.4%	20.3%	64.5%	15.9%
Low Density	6.9%	5.7%	13.4%	16.7%	57.2%
	11.9%	12.1%	11.2%	10.5%	57.9%

Table 6.19 Trip Interchange Percentages for Medium Truck Productions

	Ret	Const	Farm	HH	Govt	Ware	Trans	Off	Oth	Ind
Ret	48.8%	3.8%	3.8%	21.4%	2.1%	2.1%	2.1%	2.1%	3.8%	10.1%
Const	13.4%	19.1%	19.1%	16.7%	1.4%	1.4%	1.4%	1.4%	19.1%	6.9%
Farm	13.4%	19.1%	19.1%	16.7%	1.4%	1.4%	1.4%	1.4%	19.1%	6.9%
HH	15.1%	3.2%	3.2%	63.3%	1.3%	1.3%	1.3%	1.3%	3.2%	6.7%
Govt	21.5%	3.9%	3.9%	17.6%	10.6%	10.6%	10.6%	10.6%	3.9%	6.7%
Ware	21.5%	3.9%	3.9%	17.6%	10.6%	10.6%	10.6%	10.6%	3.9%	6.7%
Trans	21.5%	3.9%	3.9%	17.6%	10.6%	10.6%	10.6%	10.6%	3.9%	6.7%
Off	21.5%	3.9%	3.9%	17.6%	10.6%	10.6%	10.6%	10.6%	3.9%	6.7%
Oth	13.4%	19.1%	19.1%	16.7%	1.4%	1.4%	1.4%	1.4%	19.1%	6.9%
Ind	22.0%	3.7%	3.7%	9.4%	1.3%	1.3%	1.3%	1.3%	3.7%	52.2%

Table 6.20 Trip Interchange Percentages for Medium Truck Attractions

	Ret	Const	Farm	HH	Govt	Ware	Trans	Off	Oth	Ind
Ret	51.1%	14.2%	14.2%	16.5%	21.4%	21.4%	21.4%	21.4%	14.2%	21.7%
Const	3.8%	19.3%	19.3%	3.5%	4.0%	4.0%	4.0%	4.0%	19.3%	4.1%
Farm	3.8%	19.3%	19.3%	3.5%	4.0%	4.0%	4.0%	4.0%	19.3%	4.1%
HH	20.9%	15.9%	15.9%	64.5%	18.4%	18.4%	18.4%	18.4%	15.9%	6.8%
Govt	1.3%	1.4%	1.4%	1.3%	10.4%	10.4%	10.4%	10.4%	1.4%	1.3%
Ware	1.3%	1.4%	1.4%	1.3%	10.4%	10.4%	10.4%	10.4%	1.4%	1.3%
Trans	1.3%	1.4%	1.4%	1.3%	10.4%	10.4%	10.4%	10.4%	1.4%	1.3%
Off	1.3%	1.4%	1.4%	1.3%	10.4%	10.4%	10.4%	10.4%	1.4%	1.3%
Oth	3.8%	19.3%	19.3%	3.5%	4.0%	4.0%	4.0%	4.0%	19.3%	4.1%
Ind	11.1%	6.6%	6.6%	3.5%	6.6%	6.6%	6.6%	6.6%	6.6%	54.0%

6.3 HEAVY TRUCK MODEL

Trip Generation

The ATRI truck GPS data was used to adjust the existing heavy truck trip rates, friction factors and land use to land use trip interchange percentages. Table 6.21 presents the derived truck trip rates from the GPS data. It also shows the number of heavy trucks and the truck trips made by these trucks that was used to derive the truck trips per truck rate. This data was gathered from the MAG region for a period of a month in April 2011.

Table 6.21 Number of Truck Trips per Heavy Truck by Land Use from ATRI GPS Data

Land Use	Number of Truck Trips	Number of Trucks	Truck Trips per Truck
Retail	9,466	1,892	5.0032
Construction	141	66	2.1364
Farming	4,599	1,021	4.5044
Households	3,674	895	4.1050
Government	1,474	363	4.0606
Warehousing	17,064	2,551	6.6891
Transportation	97	29	3.3448
Office	562	173	3.2486
Manufacturing	12,886	1,996	6.4559
Service	620	215	2.8837
Total	**50,583**	**9,201**	

These trips are expanded to a day using the truck populations derived from 2002 VIUS and 2007 DMV registration data as mentioned in the previous section. This is shown in Table 6.22.

Table 6.22 Heavy Truck Populations in the MAG Region

Business Sector	Heavy Trucks
Agriculture	988
Construction	8,883
Manufacturing	728
Mining	225
Retail trade	10,997
Services	1,970
Transp. and Warehousing	16,824
Utilities	600
Wholesale trade	2,030
Total	**43,245**

After expanding the GPS data to MAG region, the number of expanded truck trips by land use are computed, which serves as the control or target number of trucks trips necessary for the new heavy truck model. The ratio of these expanded totals and existing heavy truck trips from the model is used as an adjustment factor. These factors are computed by land use and are applied to the existing heavy truck trip rates to come up with new updated trip rates. Table 6.23 shows the new trip rates by land use for heavy trucks. Most of these rates are identical for both productions and attractions, except for construction as indicated in the table below. Table 6.24 shows the total number of heavy truck trip ends computed by the updated truck trip rates.

Table 6.23 Heavy Truck Trip Rates

Land Use	Total Employment	Retail Employment	Retail Squared	Total Population	LN (Households)	Wholesale Employment	Mining Employment	Farming Employment	Manufacturing Employment
Retail	–	0.2562	–	–	–	–	–	–	–
Constr.	0.0033	–	–	0.0029	–	–	–	–	–
Farming	–	–	–	–	–	–	–	0.4814	–
Households	–	–	–	–	0.1966	–	–	–	–
Govt.	0.0022	–	–	–	–	–	–	–	–
Warehouse	–	–	–	–	–	1.4482	–	–	–
Transp.	–	–	–	–	–	0.0962	–	–	–
Office	0.0008	–	–	–	–	–	–	–	–
Other	0.0009	–	–	–	–	–	–	–	–
Manufac.	–	–	–	–	–	–	–	–	0.0302

Table 6.24 Heavy Truck Trip Ends

Land Use	Trip Ends
Retail	55,020
Construction	18,977
Farming	4,450
Households	2,463
Government	3,867
Warehousing	111,326
Transportation	7,396
Office	1,474
Other	1,626
Manufacturing	4,700
Total	**211,300**

Trip Distribution

Friction Factors

The heavy trucks are also distributed using an innovative gravity model, which has a similar form as that of the medium truck gravity model. The friction factors are computed using GPS truck trips and travel time skims using the in-built TransCAD procedure.

$\textit{Friction Factor}_{ij} = e^{(coeff * t_{ij})}$

Where,

Coeff = Parameter derived from observed data (-0.024);

t_{ij} = Travel time for any given 'ij' pair of zones.

The processed GPS data is used to calibrate this gravity model until the derived friction factors enabled the model to match the observed trip length frequency distributions.

Land Use to Land Use Interchanges

Similar to the medium truck trip distribution model, the land use to land use trip interchanges for heavy truck trips are first determined. These are computed from the ATRI GPS data as shown in Table 6.25. This table shows a 10 by 10 matrix of land use to land use trips made by heavy trucks in the MAG region for the month of April 2011. The trip percentages were computed from this matrix and production and attraction percentages were derived from this as shown in Tables 6.26 and 6.27.

Table 6.25 Heavy Trip Interchange Percentages from ATRI GPS Data

	Retail	Constr.	Farming	Households	Government	Warehousing	Transportation	Office	Service	Manufacturing	Total
Retail	2,958	91	758	1,165	398	3,858	21	156	233	1,226	10,864
Constr.	75	47	18	31	22	20	–	–	6	96	315
Farming	931	26	385	195	72	1,219	4	22	37	914	3,805
Hhld.	1,170	41	200	732	207	725	19	58	114	1,166	4,432
Govt.	400	29	68	182	133	162	11	23	47	654	1,709
Wrhs.	4,069	76	758	1,071	319	2,878	17	169	117	3,152	12,626
Transp.	27	1	3	16	4	47	10	1	2	17	128
Office	190	–	24	69	25	215	2	25	25	96	671
Service	229	6	35	117	34	104	2	14	24	275	840
Manuf.	2,272	96	1,140	637	410	1,455	33	125	280	8,745	15,193
Total	**12,321**	**413**	**3,389**	**4,215**	**1,624**	**10,683**	**119**	**593**	**885**	**16,341**	**50,583**

Table 6.26 Trip Interchange Percentages for Heavy Truck Productions

	Ret	Const	Farm	Min	HH	Govt	Ware	Trans	Off	Oth	Ind
Ret	27.2%	0.8%	7.0%	0.0%	10.7%	3.7%	35.5%	0.2%	1.4%	2.1%	11.3%
Const	23.8%	14.9%	5.7%	0.0%	9.8%	7.0%	6.3%	0.0%	0.0%	1.9%	30.5%
Farm	24.5%	0.7%	10.1%	0.0%	5.1%	1.9%	32.0%	0.1%	0.6%	1.0%	24.0%
Min	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HH	26.4%	0.9%	4.5%	0.0%	16.5%	4.7%	16.4%	0.4%	1.3%	2.6%	26.3%
Govt	23.4%	1.7%	4.0%	0.0%	10.6%	7.8%	9.5%	0.6%	1.3%	2.8%	38.3%
Ware	32.2%	0.6%	6.0%	0.0%	8.5%	2.5%	22.8%	0.1%	1.3%	0.9%	25.0%
Trans	21.1%	0.8%	2.3%	0.0%	12.5%	3.1%	36.7%	7.8%	0.8%	1.6%	13.3%
Off	28.3%	0.0%	3.6%	0.0%	10.3%	3.7%	32.0%	0.3%	3.7%	3.7%	14.3%
Oth	27.3%	0.7%	4.2%	0.0%	13.9%	4.0%	12.4%	0.2%	1.7%	2.9%	32.7%
Ind	15.0%	0.6%	7.5%	0.0%	4.2%	2.7%	9.6%	0.2%	0.8%	1.8%	57.6%

Table 6.27 Trip Interchange Percentages for Heavy Truck Attractions

	Ret	Const	Farm	Min	HH	Govt	Ware	Trans	Off	Oth	Ind
Ret	24.0%	22.0%	22.4%	0.0%	27.6%	24.5%	36.1%	17.6%	26.3%	26.3%	7.5%
Const	0.6%	11.4%	0.5%	100.0%	0.7%	1.4%	0.2%	0.0%	0.0%	0.7%	0.6%
Farm	7.6%	6.3%	11.4%	0.0%	4.6%	4.4%	11.4%	3.4%	3.7%	4.2%	5.6%
Min	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HH	9.5%	9.9%	5.9%	0.0%	17.4%	12.7%	6.8%	16.0%	9.8%	12.9%	7.1%
Govt	3.2%	7.0%	2.0%	0.0%	4.3%	8.2%	1.5%	9.2%	3.9%	5.3%	4.0%
Ware	33.0%	18.4%	22.4%	0.0%	25.4%	19.6%	26.9%	14.3%	28.5%	13.2%	19.3%
Trans	0.2%	0.2%	0.1%	0.0%	0.4%	0.2%	0.4%	8.4%	0.2%	0.2%	0.1%
Off	1.5%	0.0%	0.7%	0.0%	1.6%	1.5%	2.0%	1.7%	4.2%	2.8%	0.6%
Oth	1.9%	1.5%	1.0%	0.0%	2.8%	2.1%	1.0%	1.7%	2.4%	2.7%	1.7%
Ind	18.4%	23.2%	33.6%	0.0%	15.1%	25.2%	13.6%	27.7%	21.1%	31.6%	53.5%

7.0 Truck Tour-Based Model Development

This chapter provides a description of the truck tour-based model that was developed using the truck GPS data. It provides a methodology that was adopted, followed by model estimation results from each of the truck tour-based modeling components, and model calibration.

7.1 Methodology

The basic concept behind truck tour-based models is consistent with activity-based passenger models. These models focus on the tour characteristics of truck trips and are less concerned about what is being carried in the vehicle. One example of a tour-based model was developed in Calgary, Canada, which applies tour-based micro-simulation modeling concepts to urban goods movement modeling that was originally developed for passenger modeling[20]. In this model, a series of choice models are employed in order to determine the type of vehicle that will be used to conduct the business of the tour, the purpose of each stop (goods pickup or delivery, service, return to home), and the location of the next stop.

The tour-based components track the activity of trucks, and since these components will operate at the vehicle level, they will only generate estimates of a single mode[21]. Trucks are associated with establishments, and truck activity is seen as a function of the type of activity that occurs at that establishment. The tour-based components operate within zones, as do the trip-based truck models, and the activity estimates are aggregated for all of the establishments in a zone. The tour-based model described here generates the number of stops that have to be made in each zone for a particular type of truck (e.g., retail, manufacturing), and then string these trips together into tours. The number of stops on a tour, the type of stops, the location and time of day of stops are all estimated from the model based on the type of truck making the tour, the activities conducted by the truck, the characteristics of the stops, and the traffic conditions in the network.

[20] City of Calgary, 2001 Regional Transportation Model: Commercial Vehicle Model, August 2006.

[21] Fischer, M. J., An Innovative Framework for Modeling Freight Transportation in Los Angeles County, January 2005.

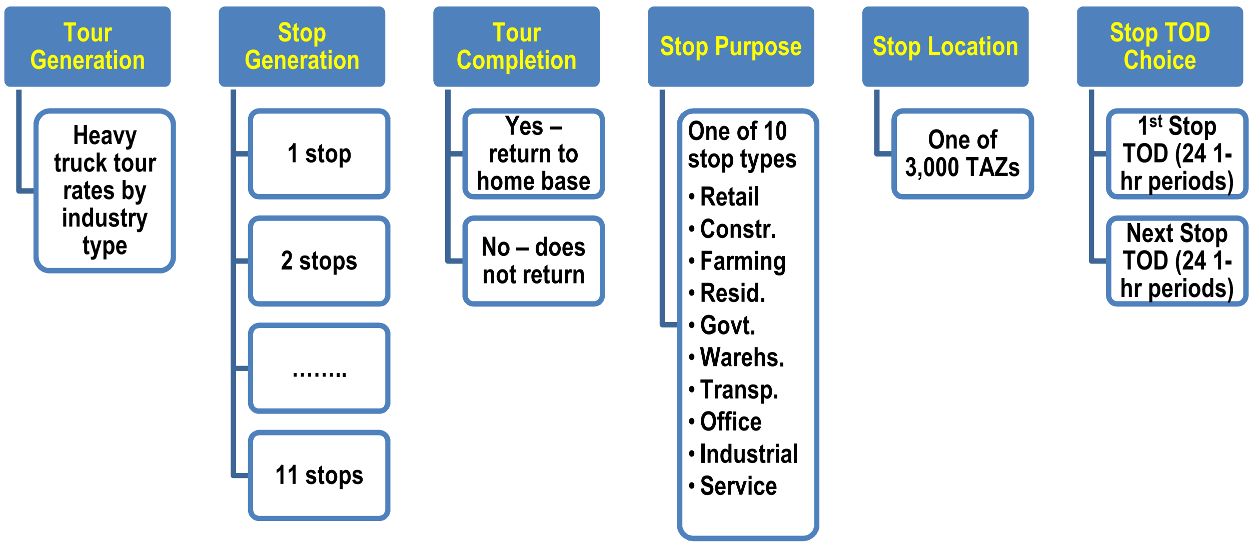
Model Estimation

There were several truck records that were eliminated due to inability to geocode, unable to find appropriate land uses, and weekend trips. So the processed GPS data yielded a truck tour database that comprises of data from 4,443 trucks that indulged in over 19,000 tours and 39,000 trips. A summary of these tours is shown below:

- **Retail** 4,238 (21.4%)
- **Construction** 80 (0.4%)
- **Farming** 1,808 (9.1%)
- **Mining** 0 (0.0%)
- **Households** 1,503 (7.6%)
- **Government** 490 (2.5%)
- **Warehousing** 6,531 (33.0%)
- **Transportation** 45 (0.2%)
- **Office** 213 (1.1%)
- **Manufacturing** 4,619 (23.3%)
- **Service** 286 (1.4%)
- **Total** **19,813** **(100.0%)**

One major assumption was that "tour purpose" was defined by the land use in the truck's starting location for the tour. That is, if a tour has a "retail" land use as the starting origin, then the whole tour is classified as a "retail tour." This is the best that could be done because the GPS data does not divulge the industry type of each truck. Upon further examining the data, it was found that the majority of the truck tours are incomplete, that is, the trucks do not return to their home base or the starting origin. Only about eight percent of truck tours completed the tour and returned to starting origin. Truck tours are modeled through a sequence of models as shown in Figure 7.1. These models include predicting tour generation at the zonal level by tour purpose (i.e., starting land use type), the number of stops for each tour, the purpose of those stops, the location of stops, and the time of day for stops.

Figure 7.1 Tour-Based Truck Model



7.2 Tour Generation

The tour generation model estimates the number of tours generated in each zone by truck tour purpose. Truck tour purpose is defined as the starting land use type of the tour. Using a combination of existing heavy truck trip rates, tour completion percentage and average stops per tour, the tour rates were computed by tour purpose. These rates are multiplied by the appropriate employment variable for each tour purpose to produce number of tours.

7.3 Stop Frequency Model

The stop frequency model predicts the number of stops on each truck tour. This is a multinomial logit (MNL) model where the number of stops are the choices that have utilities associated with it. The choices were limited to 11 stops as there were only a fraction of trucks that indulged in more than 11 stops on a single tour.

The model estimation results are presented in Table 7.1. The key variables that were found to be significant in explaining stop frequency were the starting land use of the tour and zonal land use variables. The zonal variables that influence stop making behavior are employment by type and households at the starting zone of the tour.

Table 7.1 Stop Frequency Model

Variable	Coeff.	t-stat
Constant – 2 stops	-0.8927	-26.14
Constant – 3 stops	-1.1971	-28.13
Constant – 4 stops	-1.8482	-36.60
Constant – 5 stops	-2.1850	-39.14
Constant – 6 stops	-2.7774	-42.44
Constant – 7 stops	-3.1509	-42.48
Constant – 8 stops	-3.4930	-41.40
Constant – 9 stops	-3.9498	-39.64
Constant – 10 stops	-4.2327	-37.48
Constant – 11 stops	-4.5434	-35.22
Number of Stops – Construction	0.4895	2.26
Log (No. of Stops) – Construction	-3.0722	-3.21
Number of Stops – Farming	0.1302	2.97
Log (No. of Stops) – Farming	-0.4224	-3.23
Number of Stops – Household	0.0186	1.13
Number of Stops – Government	0.1479	2.18
Log (No. of Stops) – Government	-0.3833	-1.82
Number of Stops – Warehousing	0.1958	5.41
Log (No. of Stops) – Warehousing	-0.7160	-4.01
Number of Stops – Industrial	0.2074	4.69
Log (No. of Stops) – Industrial	-0.7632	-3.16
(Total Emp. Start Zone) / (No. of Stops)	-0.0001	-4.24
(Total HHs Start Zone) / (No. of Stops)	-0.0002	-4.34
(AI to Construction Emp.) / (No. of Stops) – Construction	-2.4742	-2.54
(AI to Wholesale Emp.) / (No. of Stops) – Warehousing	-0.2225	-1.17
(AI to Manufacturing Emp.) / (No. of Stops) – Industrial	-0.2059	-1.07
Observations	**15,428**	
Log Likelihood at Zero	-36994.7283	
Log Likelihood with Constants Only	-26251.8629	
Log Likelihood at Convergence	-26191.4987	
Rho-Squared wrt Zero	0.2920	
Rho-Squared wrt Constants Only	0.0023	

Another key variable was the accessibility index that is expressed as a logarithmic function of travel time and employment at the destination end.

Accessibility Index (AI) = ln (1 + Sum_j [(exp (-0.05*TT_{ij}) / 10000) * EMP_j])

Where,

TT_{ij} is travel time between i and j; and

EMP_j is employment at the destination zone j.

7.4 Tour Completion Model

The tour completion model predicts whether the tour returns to its starting location or ends at another location. This is a binomial logit choice model with two alternatives: tour does not complete or tour completes. These results are shown in Table 7.2.

Table 7.2 Tour Completion Model

Variable	Coeff.	t-stat
Constant	-3.9129	-25.74
Tour Purpose = Construction, Transportation, Office, or Service	-1.7912	-4.48
Tour Purpose = Farming	-2.7742	-4.25
Tour Purpose = Household	-0.3716	-1.02
Tour Purpose = Government	-0.6500	-1.63
Tour Purpose = Warehouse	0.8176	4.04
Tour Purpose = Industrial	0.7998	3.67
Number of Stops on Tour	0.1123	3.26
Number of Stops – Farming Tour	0.1433	1.90
Number of Stops – Household Tour	0.1503	2.21
Number of Stops – Government Tour	0.1725	2.18
Number of Stops – Warehouse Tour	0.1468	3.84
Number of Stops – Industrial Tour	0.1641	4.17
Total Employment in Start Zone	0.0004	7.75
Total Emp. – Farming Tour	0.0007	2.56
Total Emp. – Household Tour	-0.0004	-2.48
Total Emp. – Warehouse Tour	-0.0003	-4.82
Total Emp. – Industrial Tour	-0.0003	-3.87
Observations	**15,428**	
Log Likelihood at Zero	-10,693.8747	

Variable	Coeff.	t-stat
Log Likelihood with Constants Only	-4152.1046	
Log Likelihood at Convergence	-3686.2739	
Rho-Squared wrt Zero	0.6553	
Rho-Squared wrt Constants Only	0.1122	

The tour purpose and the number of stops on the tour make a significant impact on the tour completion probability. The greater the number of stops on the tour, the less the likelihood of a tour being completed. Industrial and warehousing tours are more prone to completing the tour while farming and service trucks are less likely to completing the tour. The land use variables like employment and accessibility indices do influence the completion of the tour as they do the stop making behavior.

7.5 Stop Purpose Model

The stop purpose model predicts the purpose (i.e., land use type) of each stop that is predicted by the stop frequency model. This is a MNL model that predicts purpose of the stops in sequence, that is, from the first stop to the last stop. The alternatives or choices used in this model are the same land use types as defined in the trip-based truck model. Because there are no tour observations for mining, only the following 10 alternatives were used:

- Retail,
- Construction,
- Farming,
- Households,
- Government,
- Warehousing,
- Transportation,
- Office,
- Industrial/Manufacturing, and
- Service (or Other).

The estimated model is presented in Table 7.3. All the coefficients are segmented by tour purpose. This influences the type of stop purpose significantly. The starting land use of the tour influences the stop purpose of subsequent stops on the tour. Other key explanatory variables that were found to be significant in this model are previous stop purpose, where certain purpose to purpose interchanges are much more prevalent than others, and the number of previous stops by purpose, which includes the total number of stops of each type already simulated for the tour. The accessibility indices that are segmented by tour purpose were also found to be significant in explaining the stop purpose. The zonal land use variables including employment by type and households at the starting zone also influence the stop purpose.

Table 7.3 Stop Purpose Model

Alternative	Variable	Coeff.	t-stat
Retail	(AI to Retail Employment) / (Stop Seq. No.)	0.3542	5.37
Construction	Constant	-3.5124	-18.46
	Previous Purpose = Construction	1.8385	5.59
	Previous Purpose = Government	0.8050	3.49
	Previous Purpose = Warehouse	-0.6797	-4.54
	Previous Purpose = Office	-5.0000	Constr.
	Previous Purpose = Industrial	0.4176	2.99
	Tour Purpose = Construction	0.8725	2.34
	(AI to Construction Employment) / (Stop Seq. No.)	0.9580	6.04
	Number of Stops on Tour	-0.0701	-2.70
	Number of Previous Construction Stops on Tour	1.2190	5.58
Farming	Constant	-0.8851	-9.08
	Previous Purpose = Household	-0.3202	-3.60
	Previous Purpose = Government	-0.2924	-1.99
	Previous Purpose = Warehouse	-0.5344	-8.49
	Previous Purpose = Transportation	-1.6544	-1.64
	Previous Purpose = Office	-0.7184	-3.00
	Previous Purpose = Industrial	0.5527	9.01
	Previous Purpose = Service	-0.4474	-2.22
	Tour Purpose = Farming	0.2257	3.22
	Tour Purpose = Industrial	0.3834	6.72
	Number of Stops on Tour	0.0389	3.65
	Number of Previous Farming Stops on Tour	0.5056	10.13
	Number of Previous Warehouse Stops on Tour	0.2748	6.86
	Log(1 + Stop Seq. No.)	-0.6836	-9.57

Alternative	Variable	Coeff.	t-stat
Household	Constant	-1.6710	-12.80
	Previous Purpose = Farming	-0.6690	-6.98
	Previous Purpose = Warehouse	-0.3888	-7.76
	Previous Purpose = Industrial	-0.3222	-5.30
	Previous Purpose = Service	0.2870	2.22
	Tour Purpose = Farming	0.2429	3.26
	Tour Purpose = Household	0.4298	7.46
	Tour Purpose = Transportation	1.4188	4.44
	(AI to Households) / (Stop Seq. No.)	0.2751	5.17
	Number of Stops on Tour	0.0986	10.24
	Number of Previous Household Stops on Tour	0.2795	8.04
	Log(1 + Stop Seq. No.)	-0.1035	-1.29
Government	Constant	-3.0937	-27.07
	Previous Purpose = Construction	1.0390	4.24
	Previous Purpose = Farming	-0.6923	-4.54
	Previous Purpose = Government	0.3042	2.14
	Previous Purpose = Warehouse	-0.5769	-7.37
	Tour Purpose = Farming	0.3433	3.00
	Tour Purpose = Government	0.7976	6.35
	(AI to Total Employment) / (Stop Seq. No.)	0.3455	7.83
	Number of Stops on Tour	0.1257	9.75
	Number of Previous Government Stops on Tour	0.4729	5.84
Warehouse	Constant	0.0800	1.13
	Previous Purpose = Construction	-1.6150	-5.82
	Previous Purpose = Farming	-0.0801	-1.56
	Previous Purpose = Household	-0.8162	-14.67
	Previous Purpose = Government	-1.4950	-12.55
	Previous Purpose = Warehouse	-1.0788	-23.98
	Previous Purpose = Office	-0.1851	-1.91
	Previous Purpose = Industrial	-1.3035	-24.01
	Previous Purpose = Service	-1.1516	-8.46
	Tour Purpose = Warehouse	0.0758	2.20
	Tour Purpose = Transportation	0.8350	3.06

Alternative	Variable	Coeff.	t-stat
	Tour Purpose = Industrial	0.4611	10.04
	(AI to Wholesale Employment) / (Stop Seq. No.)	0.7901	8.93
	Number of Stops on Tour	0.0807	11.11
	Number of Previous Warehouse Stops on Tour	0.3611	12.86
	Number of Previous Industrial Stops on Tour	0.1793	9.37
	Log(1 + Stop Seq. No.)	-0.6628	-12.45
Transportation	Constant	-6.3091	-15.41
	Previous Purpose = Construction	-5.0000	Constr.
	Previous Purpose = Household	0.8515	2.72
	Previous Purpose = Government	1.4876	3.93
	Previous Purpose = Warehouse	-0.9342	-2.75
	Previous Purpose = Transportation	-1.0984	-1.81
	Previous Purpose = Industrial	0.5609	1.91
	Tour Purpose = Transportation	5.1588	11.76
	(AI to Total Employment) / (Stop Seq. No.)	0.6033	5.61
	Number of Stops on Tour	0.0967	2.17
	Number of Previous Transportation Stops on Tour	1.2871	4.46
Office	Constant	-4.0698	-24.39
	Previous Purpose = Construction	-5.0000	Constr.
	Previous Purpose = Farming	-0.8093	-3.30
	Previous Purpose = Warehouse	-0.3485	-3.28
	Previous Purpose = Office	0.3335	1.09
	Tour Purpose = Office	0.7709	2.72
	(AI to Total Employment) / (Stop Seq. No.)	0.4530	8.27
	Number of Stops on Tour	0.1186	6.28
	Number of Previous Office Stops on Tour	0.4958	2.27

Alternative	Variable	Coeff.	t-stat
Industrial	Constant	-1.5535	-19.46
	Previous Purpose = Construction	1.3063	8.31
	Previous Purpose = Farming	0.7269	10.24
	Previous Purpose = Household	0.9940	17.92
	Previous Purpose = Government	1.4186	18.46
	Previous Purpose = Warehouse	0.3000	6.24
	Previous Purpose = Industrial	2.1379	45.11
	Previous Purpose = Service	1.1876	11.55
	Tour Purpose = Farming	0.2082	3.96
	Tour Purpose = Industrial	0.5426	15.49
	(AI to Manufacturing Employment) / (Stop Seq. No.)	0.8222	11.72
	Number of Stops on Tour	0.0800	11.73
	Number of Previous Farming Stops on Tour	0.1437	3.44
	Number of Previous Warehouse Stops on Tour	0.3743	14.89
	Log(1 + Stop Seq. No.)	-0.4339	-8.52
Service	Constant	-3.4494	-14.12
	Previous Purpose = Farming	-0.7302	-3.81
	Previous Purpose = Government	0.3480	1.92
	Previous Purpose = Warehouse	-1.1883	-9.97
	Previous Purpose = Industrial	0.4451	4.85
	Previous Purpose = Service	0.3014	1.28
	(AI to Service Employment) / (Stop Seq. No.)	0.5683	6.22
	Log(1 + Stop Seq. No.)	0.4144	3.15
Observations		**39,980**	
Log Likelihood at Zero		-92057.3520	
Log Likelihood with Constants Only		-68634.4347	
Log Likelihood at Convergence		-63080.2635	
Rho-Squared wrt Zero		0.3148	
Rho-Squared wrt Constants Only		0.0809	

7.6 Stop Location Choice Model

The stop location choice model predicts the location of each stop simulated for the tour, and is similar in design to a destination choice model employed for distributing passenger trips. Every zone in the region is a potential choice for this model. Similar to any other destination choice model, size variables are included in the model. These include employment at the stop location by type.

Two types of accessibility variables are included in the model:

1. Direct zone-to-zone accessibility variables or travel time between: a) previous stop location to current stop location, and b) first stop location to current stop location; AND
2. Aggregate accessibility measures. This is important to describe the accessibility of a stop zone to employment types corresponding to the next stop purpose.

Other variables include zonal area type such as CBD, rural, and suburban. This is defined as a combination of employment and population density. Most of these variables are segmented by the starting land use of the tour, previous stop purpose, current stop purpose, and number of stops on tour by purpose. These results are shown in Table 7.4.

Table 7.4 Stop Location Choice Model

Variable	Coeff.	t-stat
Utility		
Intrazonal with Previous Stop	1.9438	16.89
Intrazonal with Tour Start Zone	3.2847	25.13
Intrazonal with Previous Stop & Tour Start Zone	-4.2323	-29.50
Intrazonal with Previous Stop – Stop Purpose = WHL,MNF	-0.9357	-7.71
Intrazonal with Tour Start Zone – Stop Purpose = WHL, MNF	0.4606	3.41
Intrazonal with Previous Stop – Prev. Purpose = WHL, MNF	-0.4074	-3.33
Intrazonal with Tour Start Zone – Prev. Purpose = WHL, MNF	0.1540	1.13
Log(1 + Pk Travel Time)	-1.9154	-89.84
Log(1 + Pk Travel Time) – Total Stops on Tour >= 3	-0.2284	-7.14
Log(1 + Pk Travel Time) – First Stop on Tour, Total Stops on Tour >= 2	0.0919	3.44
Log(1 + Pk Travel Time) * Total Stops on Tour	-0.0248	-4.59
Log(1 + Pk Return Travel Time) / (Stops Remaining + 1) – Total Stops on Tour >=2	-0.3907	-14.99
AI to Retail Employment – HH stop, RET next stop	0.9715	2.37
AI to Farming Employment – FRM next stop	2.2147	10.16

Variable	Coeff.	t-stat
AI to Total Employment – HH stop, GOV next stop	2.7709	2.83
AI to War. Emp. + AI to Ind. Emp. – WHL stop	0.6668	16.12
AI to Warehouse Employment – Transportation Stop	2.2925	2.95
AI to Total Employment – HH stop, OFF next stop	3.3334	2.03
AI to War. Emp. + AI to Ind. Emp. – MNF stop	0.5931	15.48
AI to Service Employment – HH stop, SRV next stop	2.6099	2.33
Size		
Retail Stop, Retail Emp.	0.0000	n/a
Retail Stop, Total Emp.	-3.0102	-64.31
Construction Stop, Construction Emp.	0.0000	n/a
Construction Stop, Total Emp.	-1.2670	-4.36
Farming Stop, Farming Emp.	0.0000	n/a
Farming Stop, Total Emp.	-2.2886	-15.00
Household Stop, Households	0.0000	n/a
Government Stop, Total Emp.	0.0000	n/a
Wholesale Stop, Warehouse Emp.	0.0000	n/a
Wholesale Stop, Total Emp.	-4.7998	-51.12
Wholesale Stop, Industrial Emp.	-1.1768	-15.30
Transportation Stop, Total Emp.	0.0000	n/a
Office Stop, Total Emp.	0.0000	n/a
Manufacturing Stop, Industrial Emp.	0.0000	n/a
Manufacturing Stop, Total Emp.	-3.8941	-43.09
Manufacturing Stop, Warehouse Emp.	0.9711	15.37
Service Stop, Service Emp.	0.0000	n/a
Observations	**39,803**	
Log Likelihood at Zero	-156498.4557	
Log Likelihood at Convergence	-69679.2453	
Rho-Squared wrt Zero	0.5548	

7.7 STOP TIME OF DAY CHOICE MODEL

The stop time of day choice model predicts the time period of each stop on a tour. Two separate models were estimated for time of day choice. The first is used for the departure time of a tour's first trip, and the second is used for subsequent trips. The reason for defining two separate models is that subsequent trip departure times should depend, in part, on the timing of a tour's previous trips. Thus, duration between trips is an important variable in the subsequent time of day choice model. Both models are MNL models, where the alternatives include each one-hour period of the day (24 alternatives in total). In application, the one-hour periods are aggregated back to the four existing time periods used in the regional model – AM peak, mid-day, PM peak and night.

There are two main reasons for defining the alternatives as one-hour periods rather than the four existing time periods used in MAG's regional model. First, this ensures alternatives are of uniform size, and no special considerations are needed to adjust variables for the size. Second, the more refined time period definitions should allow travel time between stops to have important implications. In addition, it allows availability restrictions to be more well-defined for the subsequent stop period model. Since truckers involved in interstate commerce are not allowed to work more than 12 consecutive hours by law, availability restrictions are important.

The following variables were found to be significant in the time of day choice models shown in Tables 7.5 and 7.6:

- Starting land use for the tour;
- Previous and current stop purpose;
- Number of stops on tour by purpose;
- Travel distance/time from previous stop to current stop; and
- Previous stop time of day (if not first stop).

Table 7.5 Time of Day Choice Model – First Trip

TOD Period	Segment	Variable	Coeff.	t-stat
AM	All	Constant	-0.8526	-4.07
AM	Tour Purpose = FRM, WHL, or MNF	Constant	0.6694	4.29
AM	First Stop Purpose = FRM, WHL, or MNF	Constant	0.4608	5.14
AM	All	Total Stops on Tour	0.1865	4.77
AM	Tour Purpose = FRM, WHL, or MNF	Total Stops on Tour	-0.2781	-5.65
AM	All	Log(1 + Pk Travel Time to First Stop)	-0.2832	-5.69
MD	All	Constant	-1.8406	-19.13
MD	First Stop Purpose = FRM, WHL, or MNF	Constant	0.1810	4.27

TOD Period	Segment	Variable	Coeff.	t-stat
MD	All	Total Stops on Tour	0.2812	16.20
MD	Tour Purpose = FRM, WHL, or MNF	Total Stops on Tour	-0.0718	-3.68
MD	All	Indicator for Completed Tour	0.6124	8.96
MD	All	Log(1 + Pk Travel Time to First Stop)	0.1739	6.89
MD	All	MD Shift Variable	0.4333	23.44
MD	Tour Purpose = FRM, WHL, or MNF	MD Shift Variable	-0.1189	-5.72
PM	All	Constant	0.5981	6.23
PM	Tour Purpose = FRM, WHL, or MNF	Constant	-0.4432	-5.53
PM	All	Total Stops on Tour	0.1884	10.41
PM	Tour Purpose = FRM, WHL, or MNF	Total Stops on Tour	-0.0491	-2.32
PM	All	Log(1 + Pk Travel Time to First Stop)	0.0901	4.06
PM	All	PM Shift Variable	-0.1309	-6.19
PM	Tour Purpose = FRM, WHL, or MNF	PM Shift Variable	0.1111	4.14
NT	All	NT Shift Variable Early	-0.0953	-5.46
NT	Tour Purpose = FRM, WHL, or MNF	NT Shift Variable Early	-0.0417	-2.00
NT	All	NT Shift Variable Late	0.1375	10.53
NT	Tour Purpose = FRM, WHL, or MNF	NT Shift Variable Late	-0.0314	-2.04
Observations			**15,196**	
Log Likelihood at Zero			-48293.7060	
Log Likelihood wrt Constants Only			-46068.1240	
Log Likelihood at Convergence			-45539.7836	
Rho-Squared wrt Zero			0.0570	
Rho-Squared wrt Constants			0.0115	

Table 7.6 Time of Day Choice Model – Subsequent Trips

Variable	Coeff.	t-stat
Constant – Same 1-hr Period as Previous Stop	-2.881	-8.1
Constant – First 1-hr Period after Previous Stop	-1.664	-5.2
Constant – Second 1-hr Period after Previous Stop	-1.742	-6.1
Constant – Third 1-hr Period after Previous Stop	-1.775	-7.0
Constant – Fourth 1-hr Period after Previous Stop	-1.701	-7.7
Constant – Fifth or Sixth 1-hr Period after Previous Stop	-1.497	-8.4
Constant – Seventh or Eighth 1-hr Period after Previous Stop	-1.138	-8.9
Departure Time Shift Variable [a]	-0.946	-21.5
Departure Shift – Prev. Stop = Construction	0.150	1.7
Departure Shift – Prev. Stop = Warehouse	0.075	6.8
Departure Shift – Prev. Stop = Transportation	-0.159	-1.6
Departure Shift – Prev. Stop = Manufacturing	0.102	5.7
Departure Shift * Log (1 + Peak Travel Time to Previous Stop)	0.144	28.7
Departure Shift * Total Number of Stops on Tour	-0.042	-17.9
Departure Shift * Construction Stops on Tour	-0.069	-2.7
Departure Shift * Households Stops on Tour	-0.031	-4.8
Departure Shift * Government Stops on Tour	-0.037	-3.5
Departure Shift * Service Stops on Tour	-0.053	-3.4
Time / Stops Remaining [b]	0.037	2.0
Time / Stops Remaining – Prev. Stop = Construction	0.183	1.7
Time / Stops Remaining – Prev. Stop = Farming	0.083	3.0
Time / Stops Remaining – Prev. Stop = Manufacturing	0.047	1.9
Observations	**22,648**	
Log Likelihood at Zero	-58935.4	
Log Likelihood with Constants Only	-53945.6	
Log Likelihood at Convergence	-34386.3	
Rho-Squared wrt Zero	0.417	
Rho-Squared wrt Constants Only	0.363	

[a] This variable is equal to the number of periods the alternative is after the departure period of the previous stop.

[b] This variable is computed as (16 – Departure Shift wrt First Trip Departure Period) / (1 + Total Number of Stops Remaining).

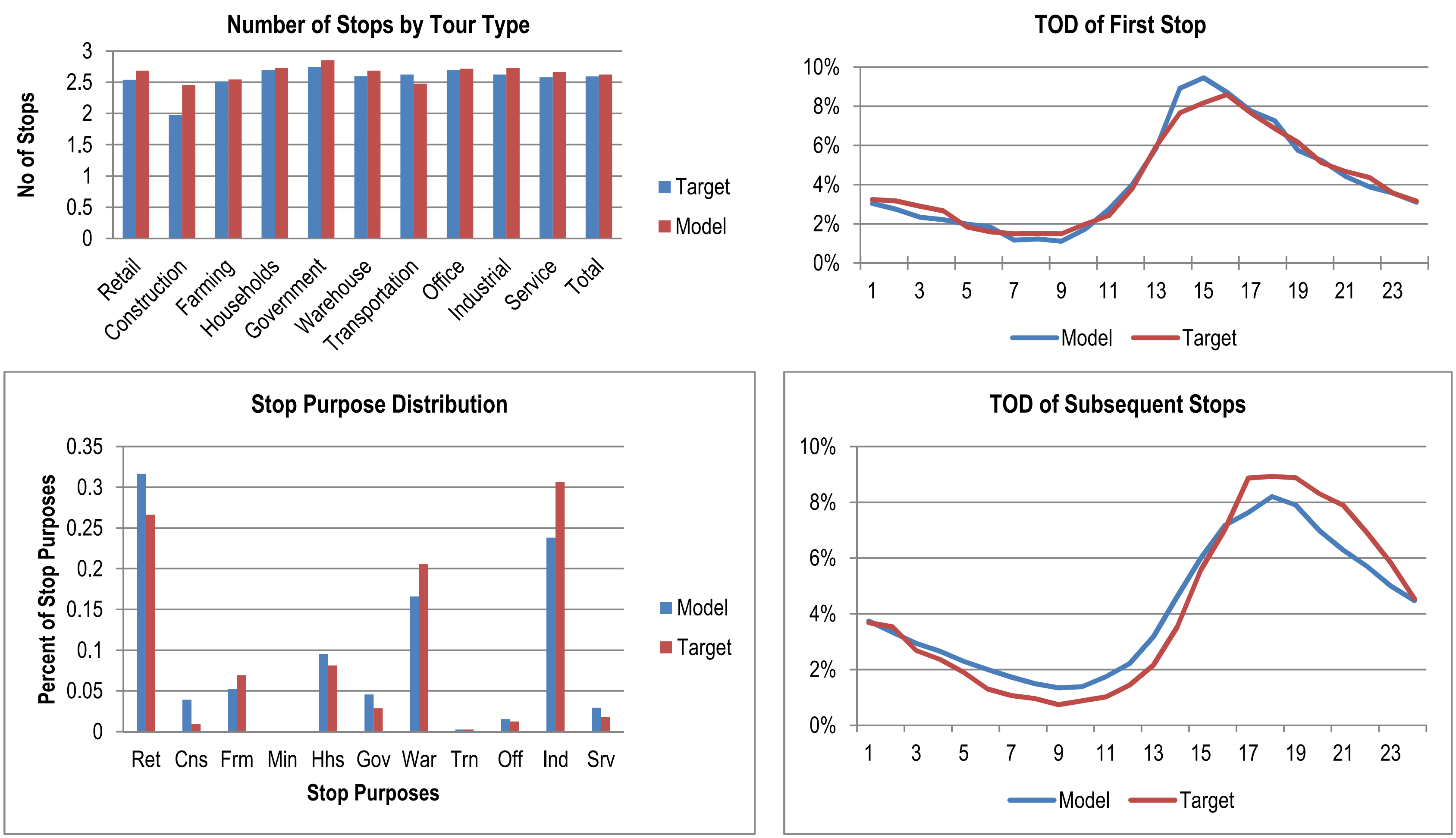
7.8 Tour Model Calibration

All the tour model components were coded in GISDK and implemented in TransCAD. Each component was individually assessed and calibrated. The reasonability of the explanatory variables were determined by their magnitude, t-statistic and their relation to the dependent variable. Some of the key findings include:

- Construction tours are less prone to making more stops, while government-related tours have a higher propensity to making more stops;
- More number of stops on a tour make the truck less likely to complete the tour;
- Stop purpose is often strongly influenced by the tour type or the first land use of the truck origin;
- Travel time has a negative effect on location choice utility, and is more pronounced as the number of stops on tour increase; and
- Previous stop purpose has a significant impact on the time period of the next stop.

The individual model outputs were also compared against the truck GPS data to assess the model performance. These results are depicted in Figure 7.2. These comparisons indicate that the model components are predicting very closely to the observed data for the most part. There are some differences which can be further improved upon with more rigorous calibration and validation of the model.

Figure 7.2 Tour Model Outputs vs. Truck GPS Data



8.0 Model Calibration and Validation

This chapter provides a description of the model calibration process for each truck modeling component. It also presents the results from each calibrated model and a summary of assignment results that compares the model volumes against the classification counts.

8.1 External Truck Model

The external productions (outbound) and attractions (inbound) are generated by the regression equations, that is, the internal end of these trips are determined at the generation step. These trip ends are then balanced or forced to match the external station counts that are the targets at the other end of these trip ends. The process employed is called Frataring inside TransCAD where the external station counts are provided as inputs to the process. The procedure scales the productions and attractions (in truck trips) such a way that the external truck trip tables (EI and IE) match the external station counts along the external stations along the MAG modeling boundary. This is explained in more detail in Chapter 4. The external-external (EE) 'thru' truck trip table was also derived using the external station counts, and this is also presented in Chapter 4.

Tables 8.1 and 8.2 provide a summary of the external truck model along the external stations. Table 8.1 presents the external model results – inbound and outbound daily truck trips – compared against external station counts along each of the 13 external stations. The percent differences are all within the reasonable limits (20 percent or less) for all but four stations, namely, 3, 4, 6 and 7. Stations 3 and 6 carry relatively small volumes and hence the large percent differences.

Table 8.2 presents the external truck model results by truck class and direction of flow compared against observed vehicle classification counts. All the three truck classes are within ten percent of the observed counts, and the directional differences are within seven percent for all truck classes combined.

Table 8.1 External Truck Trips Summary by External Stations

EXT Station ID	Street Name	Direction	From	To	Inbound Count	Outbound Count	Inbound Model	Outbound Model	Percent Diff (Model – Count)
1	SR 85 South	SB	North of Mead Rd	North of Mead Rd	539	557	560	561	2%
2	I-10 Fwy	WB	Avenue 75 E	W Salome Rd	9,009	8,445	7,822	7,853	-10%
3	SR 77	NB	North of Winkelman	North of Winkelman	682	909	1,558	1,558	96%
4	SR 77	SB	South of Eagle Crest Ranch Rd	North of E Pinto Ln	11,264	10,573	7,045	7,048	-35%
5	US 60 East Hwy	EB	near mountain pass	West of Miami	3,789	3,917	4,203	4,210	9%
6	SR 188	SB	Stagecoach Trail	SR 288	742	589	452	451	-32%
7	SR 87 North	NB	North of Gisela Rd	South of Payson	4,490	4,997	8,480	8,480	79%
8	I-17 Fwy	NB	North of Coldwater Rd	North of Coldwater Rd	12,985	13,391	13,144	13,305	0%
9	SR 89 North	NB	Past Yarnell	North of Young Ln	1,001	1,055	1,169	1,238	17%
10	US 93 North	NB	Past Wickenburg	North of Date Creek Ranch Rd	2,994	3,432	2,593	2,591	-19%
11	US 60 West Hwy	WB	West of Aguila	East of Weden	640	656	560	557	-14%
12	I-10 Fwy	SB	South of Marana Airpark Rd	W Tangerine Rd	21,663	22,286	19,397	18,782	-13%
13	I-8 Fwy	WB	Avenue 76 E	S Agua Caliente Rd	4,105	4,030	3,235	3,266	-20%
Total					**73,903**	**74,837**	**70,219**	**69,901**	**-6%**

Table 8.2 Summary of External Truck Trips by Truck Class

Truck Type	Counts	Model	Difference
LT_IB	56,323	52,830	-6%
MT_IB	3,726	3,969	7%
HT_IB	13,854	13,420	-3%
LT_OB	56,458	52,505	-7%
MT_OB	3,468	3,973	15%
HT_OB	14,911	13,422	-10%
Light	112,781	105,335	-7%
Medium	7,194	7,943	10%
Heavy	28,765	26,842	-7%
Total_IB	**73,903**	**70,219**	**-5%**
Total_OB	**74,837**	**69,901**	**-7%**

8.2 Internal Truck Model

The internal truck model captures the movement of internal-internal truck trips that have both origin and destination within the MAG modeling boundary. The three truck classes have separate sets of trip rates by industry sector (or land use) and also have separate gravity models. The two sets of parameters that were adjusted during calibration were trip rates and friction factors. This was to get the average trip lengths match the observed value and the assignment results to match the observed counts (as described in the next section).

Light Commercial Trucks

The light commercial truck model based on a thorough literature review and the parameters were derived using borrowed data. Therefore, there is no independent data source to calibrate the light truck model but instead only reasonableness checks were performed.

Trip Generation

The fleet size and number of light truck trip ends were derived using a set of fleet rates and VMT per vehicle rate. The estimated number of light commercial trucks is 236,018, as shown in Table 6.10, is reasonably close (10 percent) to the DMV estimate of 215,000 of this class of trucks. Also, the computed total light truck VMT from the new model is 12.33 million which is very close to the previous model's estimate of 11.67 million, both accounting for about 13 percent of the total VMT in the region. These statistics are very reasonable and in line with general expectations. During calibration of the auto passenger model, the light truck trip rates were adjusted such that the combination of the volumes of auto passengers using light trucks plus the commercial light truck volumes matched well with the observed Class 3 counts. Table 8.3 shows the calibrated light truck trip rates and light truck trips by category.

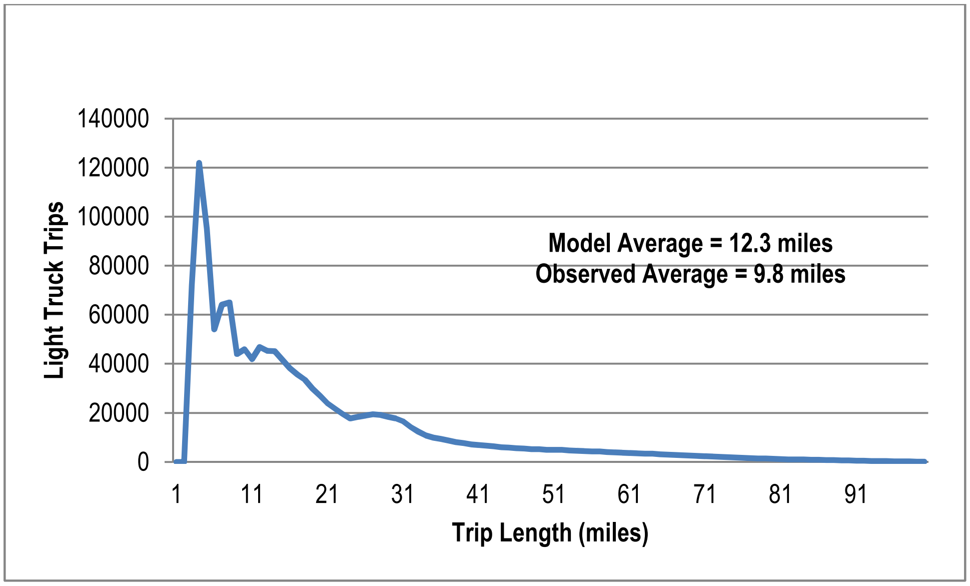
Table 8.3 Final Light Truck Trip Rates and Trip Ends

Land Use	Trip Rate	Trip Ends
Package, Product, and Mail Delivery (USPS, UPS, FedEx)	0.0300	52,973
Urban Freight Distribution, Warehouse Deliveries	0.1530	693,744
Construction Transport	0.0553	97,646
Safety Vehicles: Police, Fire, Building Inspections, Tow Trucks	0.0049	22,218
Utility Vehicles: Trash, Meter Readers, Maintenance, Plumbers, Electricians	0.0053	24,032
Public Service: Federal, State, City, Local Government	0.0248	112,450
Business and Personal Services: Personal transportation, Realtors, Door-to-Door Sales	0.0900	408,085
Total Light Truck Trip Ends		**1,411,147**

Trip Distribution

The average trip length from literature was found to be 11.9 miles for light commercial trucks, which is close to the previous model's trip length of 9.8 miles. The gravity model for light trucks was calibrated to match the 9.8 mile trip length, and Figure 8.1 shows the trip length frequency distribution of light trucks in the calibrated model.

Figure 8.1 Light Truck Trip Length Frequency Distribution



Medium Trucks

As there was no new data to estimate medium truck model parameters, the existing model was calibrated to match the observed (medium) counts at the assignment stage. In the process, the existing rates were modified and friction factors were calibrated.

Trip Generation

The existing trip rates were increased such a way that the medium truck volumes along screenlines and major freeways were close to the observed medium truck counts. This was the only way to calibrate the trip generation model. The final medium truck trip rates and truck trip ends are shown in Tables 8.4 and 8.5.

Table 8.4 Final Calibrated Medium Truck Trip Rates

Land Use	Total Employment	Retail Employment	Retail Squared	Total Population	LN (Households)	Wholesale Employment	Mining Employment	Farming Employment	Manufacturing Employment
Retail	–	0.0721	0.00008	–	–	–	–	–	–
Constr.	0.0249	–	–	0.0134	–	–	–	–	–
Farming	–	–	–	–	–	–	–	0.6801	–
Households	–	–	–	–	2.2931	–	–	–	–
Govt.	0.0028	–	–	–	–	–	–	–	–
Warehouse	–	–	–	–	–	1.4719	–	–	–
Transp.	–	–	–	–	–	0.0354	–	–	–
Office	0.0028	–	–	–	–	–	–	–	–
Other	0.0028	–	–	–	–	–	–	–	–
Manufac.	–	–	–	–	–	–	–	–	0.0375

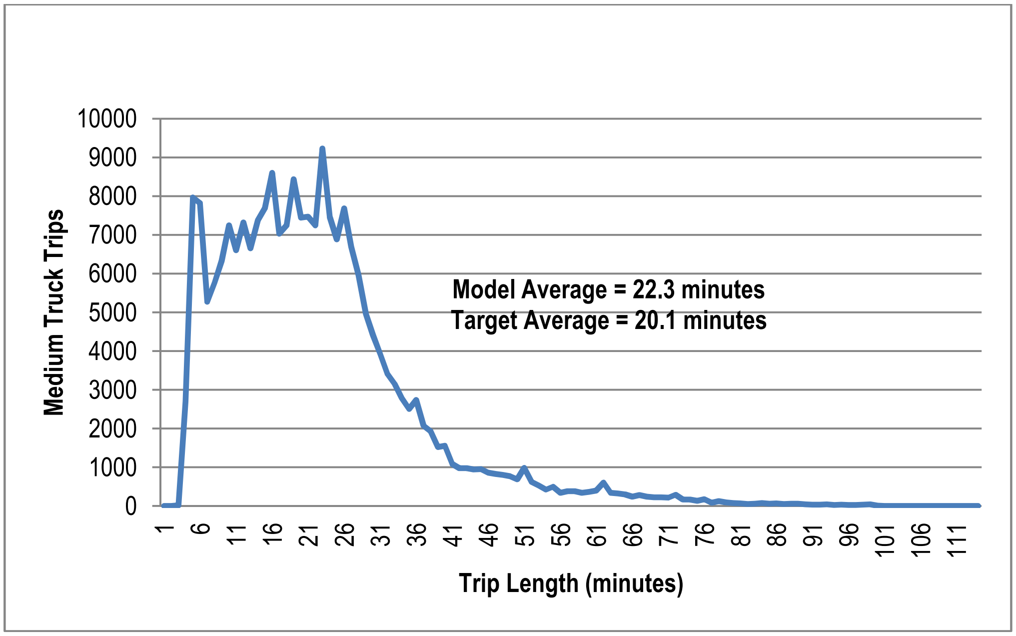
Table 8.5 Final Medium Truck Trip Ends

Land Use	Trip Ends
Retail	18,380
Construction	79,537
Farming	4,835
Households	21,754
Government	3,869
Warehousing	87,950
Transportation	2,113
Office	3,869
Other	3,869
Manufacturing	4,545
Total	**230,722**

Trip Distribution

The only source of average trip length for medium trucks was from the previous 2007 truck trip diary surveys. This estimate of 20.1 minutes was set as target and the medium truck friction factors were calibrated until the gravity model matched the target. The modeled average trip length is 22.3 minutes as shown in Figure 8.2.

Figure 8.2 Medium Truck Trip Length Frequency Distribution



Heavy Trucks

The heavy trucks were modeled based on the ATRI GPS data. This included estimating trip rates by land use as well as developing land use to land use trip interchanges for the trip distribution model. The ATRI GPS data was used as a source for calibrating the heavy truck model parameters.

Trip Generation

The estimated trip rates were adjusted to ensure the heavy truck volumes along screenlines and major freeways were close to the observed heavy truck counts. The final heavy truck trip rates and truck trip ends are shown in Tables 8.6 and 8.7.

Table 8.6 Final Calibrated Heavy Truck Trip Rates

Land Use	Total Employment	Retail Employment	Retail Squared	Total Population	LN (Households)	Wholesale Employment	Mining Employment	Farming Employment	Manufacturing Employment
Retail	–	0.1537	–	–	–	–	–	–	–
Constr.	0.0020	–	–	0.0018	–	–	–	–	–
Farming	–	–	–	–	–	–	–	0.2889	–
Households	–	–	–	–	0.1180	–	–	–	–
Govt.	0.0013	–	–	–	–	–	–	–	–
Warehouse	–	–	–	–	–	0.8689	–	–	–
Transp.	–	–	–	–	–	0.0577	–	–	–
Office	0.0005	–	–	–	–	-	–	–	–
Other	0.0006	–	–	–	–	-	–	–	–
Manufac.	–	–	–	–	–	-	–	–	0.0181

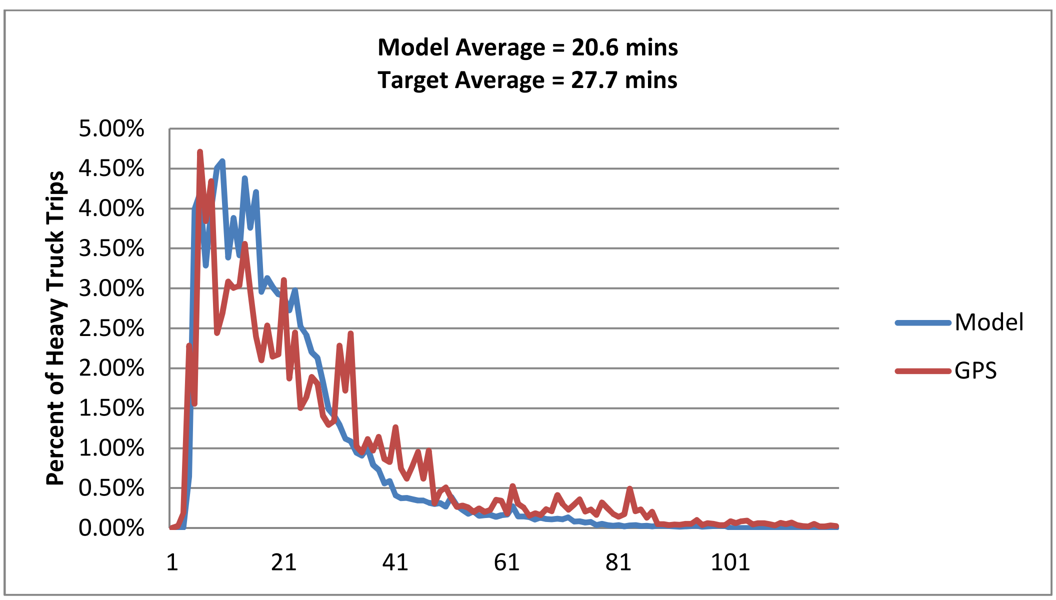
Table 8.7 Final Heavy Truck Trip Ends

Land Use	Trip Ends
Retail	32,578
Construction	11,208
Farming	2,644
Households	1,441
Government	2,304
Warehousing	66,847
Transportation	4,441
Office	878
Other	969
Manufacturing	2,826
Total	**126,136**

Trip Distribution

The average trip length and trip length frequency distribution were derived from the ATRI GPS data, which was used to calibrate the heavy truck gravity model. The target value was 27.7 minutes and the heavy truck friction factors were calibrated until the gravity model was close enough to the this value. Figure 8.3 presents the trip length frequency distribution of heavy trucks.

Figure 8.3 Heavy Truck Trip Length Frequency Distribution



8.3 TRIP ASSIGNMENT RESULTS

The internal and external truck trip tables were combined but the truck classes – light, medium and heavy – were retained. These three classes of vehicle trip tables were then assigned with the passenger auto trip tables in a multiclass equilibrium assignment. Several assignment runs were performed until the total truck volumes were validated against observed data. The validation performance measures of the model are described in the following sections.

Multiclass Assignments

Trip assignment of the truck trips was completed using a user equilibrium highway assignment. Truck trips were assigned simultaneously with the passenger trips, because congestion has a significant impact on travel times experienced by trucks. Truck trips are assigned separately by type using the multiclass assignment technique for five vehicle types:

1. Single-occupant passenger vehicles,
2. High-occupant passenger vehicles with two or more occupants,
3. Light commercial trucks,
4. Medium trucks, and
5. Heavy trucks.

Passenger Car Equivalents

The original truck model (1992) was developed using a conversion of truck volumes to passenger car equivalents (PCE) for assignment purposes. This factor provides a means to account for the fact that larger trucks take up more capacity on the roads than passenger cars. However, this process was changed in the previous model update (2007-2009), that is, the existing model does not use any PCEs; vehicles, and not PCEs, are assigned to the highway network. The use of PCEs is a fundamental change in the assignment model that has larger implications on link capacity, and on the validation and route choice of autos and trucks. Therefore, this was not implemented in this round of the model update.

Validation

The assignment validation is done at three different levels of geography.

Screenlines in Maricopa County

This includes most of the major freeways that pass through the region and carry a large volume of trucks in the region. These freeways include I-17 W, I-17 E, I-10 N and I-10 S. Also included in these screenlines are Agua Fria, which is the river that flows through the west side of the MAG region while Salt River flows just south of the Phoenix metro area. 'Commodity' screenline encompasses the

PHX regional airport and is intended to capture the cargo flows in and out of the airport facilities.

Table 8.8 presents the percent differences between the model and the observed screenline counts in Maricopa County. These results are shown by screenline, truck type and direction. Except for a few locations, most of the differences are well within the allowable limit of 25 percent, and in fact, overall, the model predicts well within ten percent along all but one screenline.

Table 8.8 Summary of Screenlines in Maricopa County

SL ID	**2**	**3**	**4**	**5**	**6**	**7**	**9**
SL Name	I-17 W	I-17 E	I-10 N	I-10 S	Agua Fria	Salt River	Commodity
LT_NE	-2%	8%	-4%	3%	11%	1%	3%
MT_NE	-11%	5%	-11%	17%	-1%	3%	4%
HT_NE	-16%	1%	4%	-21%	-29%	43%	37%
LT_SW	3%	9%	-4%	2%	13%	-1%	3%
MT_SW	-12%	9%	-24%	0%	7%	-11%	16%
HT_SW	-30%	-12%	9%	-19%	-23%	22%	43%
MT+HT_NE	-13%	4%	-6%	-2%	-17%	16%	16%
MT+HT_SW	-21%	0%	-14%	-9%	-10%	0%	26%
Total_NE	**-2%**	**8%**	**-5%**	**2%**	**9%**	**2%**	**4%**
Total_SW	**1%**	**8%**	**-4%**	**1%**	**12%**	**-1%**	**5%**

Screenlines in Pinal County

This includes highways that pass through Pinal County and the periphery of the MAG region, including external stations. These I-8, SR-177, I-10 E/W, and all external stations combined. Table 8.9 presents the percent differences between the model and the observed screenline counts in Pinal County. These results are shown by screenline, truck type and direction. These are largely low volume screenlines, and so a larger percent difference is still considered within allowable limits. Overall, the differences are well within the allowable limit of 25 percent, except for Screenline # 1 (I-8 SW).

Table 8.9 Summary of Screenlines in Pinal County

SL ID	**1**	**2**	**3**	**4**	**5**	**7**
SL Name	I-8	SR 177	North Boundary	I-10 W	I-10 E	External Station
LT_NE	-17%	3%	16%	-4%	-6%	2%
MT_NE	-53%	63%	-14%	58%	33%	-15%
HT_NE	-78%	1%	-17%	4%	9%	1%
LT_SW	-29%	2%	11%	-3%	-9%	4%
MT_SW	-53%	8%	-8%	40%	36%	-8%
HT_SW	-83%	-8%	-22%	-7%	2%	-7%
MT+HT_NE	-66%	15%	-16%	18%	16%	-2%
MT+HT_SW	-71%	-3%	-16%	6%	12%	-7%
Total_NE	**-26%**	**5%**	**13%**	**-1%**	**-3%**	**1%**
Total_SW	**-36%**	**1%**	**9%**	**-2%**	**-6%**	**1%**

Freight Corridors

The key freight corridors were also looked into during assignment validation. These determine the overall performance of the freight model in the region in terms of the total freight flows across the region. These corridors include I-10 which carries a lot of freight all the way from West Coast to the East Coast passing through the Phoenix metropolitan region. Other corridors of significance include I-17, which connects I-10 in the south and I-40 in the north (outside of MAG region). State roads include SR 51 hat runs parallel to I-17 but within the Phoenix metro area and US 60, which is a East-West highway connecting Phoenix and the suburb of Mesa. In addition, couple of loop roads L101 and L202 are also included here. This is mostly to examine the movement of local truck traffic within the MAG region.

Table 8.10 presents the results from the model assignment along these key freight corridors. There are some significant differences along loop roads L101 and L202 for heavy trucks in both directions, which could be due to the fact that these facilities do not carry a large volume of heavy trucks. However, in aggregate the model performs well along these loop roads where the differences are well within ten percent. The two major freight corridors, I-10 (East-West) and I-17 (North-South), are within six percent of the observed counts, and overall with all locations combined, the model predicts within half a percent of the observed count.

Table 8.10 Summary of Freight Corridors

Summary	I-10	L101	I-17	US 60	L202	SR 51	All
EB_LT	-1%	-6%	6%	8%	-6%	-4%	0%
EB_MT	25%	24%	-4%	13%	-26%	-49%	3%
EB_HT	6%	202%	23%	62%	97%	166%	30%
EB_MT+HT	14%	60%	8%	27%	-5%	-31%	15%
WB_LT	1%	-6%	1%	17%	-8%	-9%	-2%
WB_MT	19%	29%	3%	-11%	-30%	-28%	5%
WB_HT	14%	213%	14%	8%	79%	262%	31%
WB_MT+HT	16%	66%	8%	-5%	-11%	-1%	16%
All	**6%**	**5%**	**4%**	**12%**	**-7%**	**-8%**	**0%**

Summary of All Locations

In conclusion, the sum of truck volumes at all locations were compared against the observed counts by truck class. These are presented in Table 8.11. The light trucks are combined with passenger cars in this as there is no way to separate out light non-commercial vehicles from light commercial vehicles, and these are within two percent. The medium and heavy trucks are within four percent and ten percent, respectively, and overall, the model predicts within two percent of the observed counts.

Table 8.11 Summary of All Trucks at All Locations

Truck Class	Data	Model	Percent Difference
LT+PC	11,248,731	11,341,668	1%
MT	554,673	569,407	3%
HT	430,203	375,874	-13%
MT+HT	984,876	945,281	-4%
All	**12,233,607**	**12,286,950**	**0%**